

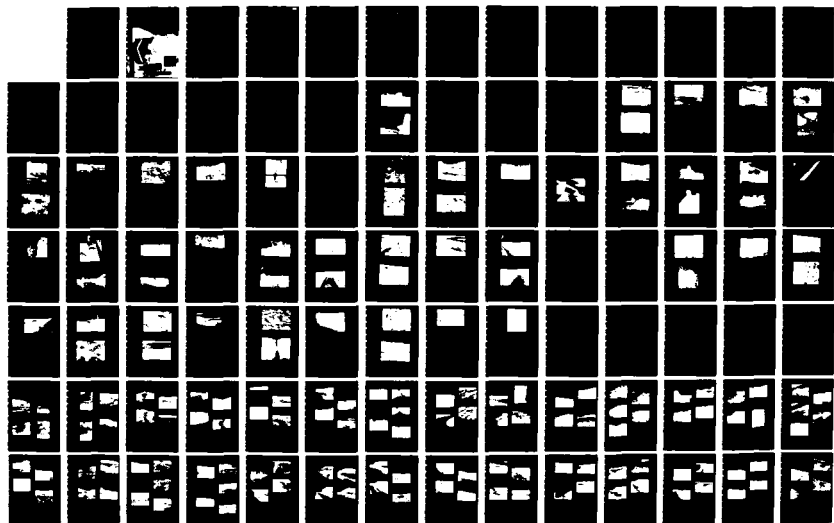
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REVEGETATION AND SELECTED TERRAIN DISTURBANCES ALONG  
THE TRANS-ALASKA PIPELINE 1975-1978(U) COLD REGIONS  
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## *Revegetation and selected terrain disturbances along the trans-Alaska pipeline, 1975-1978*

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*Cover: Slope along trans-Alaska pipeline, at Squirrel Creek near Tonsina, about 50 miles north of Valdez, September 1978. Steep slope terraced and revegetated to control erosion. (Photograph by L. Johnson.)*



## *Revegetation and selected terrain disturbances along the trans-Alaska pipeline, 1975-1978*

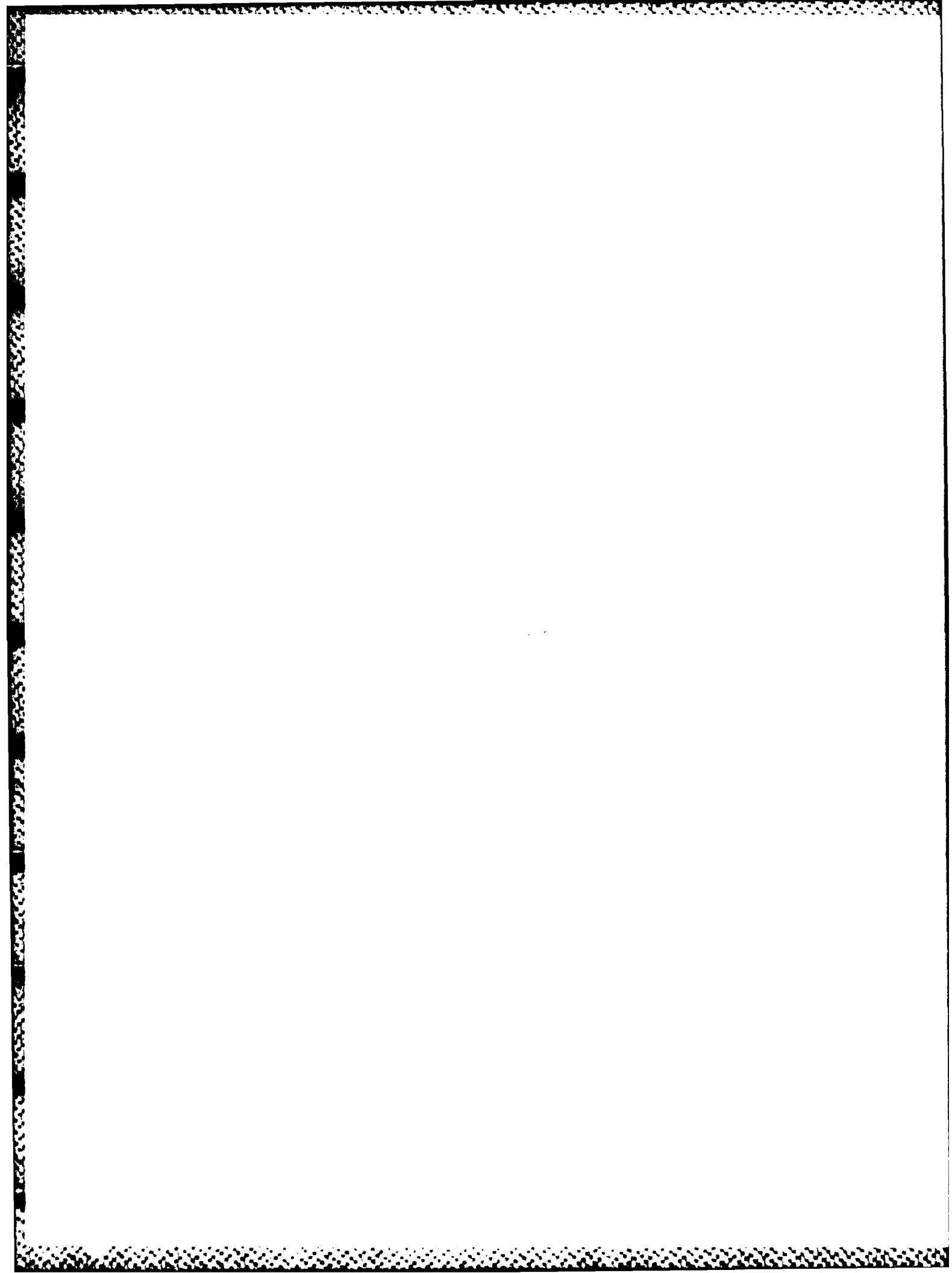
Lawrence A. Johnson

June 1981

Prepared for  
OFFICE OF THE CHIEF OF ENGINEERS  
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By  
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COLD REGIONS RESEARCH AND ENGINEERING LABORATORY  
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favorable growing conditions. Terrain disturbances due to the construction of the fuel gas line, snowpads, and oil spills were examined to identify and describe related environmental impacts on natural vegetation. Proper construction and use of snowpads minimized the extent and severity of disturbance. Crude oil spills, although damaging to vegetation, did not cause total kill of vegetation, and certain types of spills may have only short-term effects. Results of restoration research by CRREL along the trans-Alaska pipeline are discussed.



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The report was technically reviewed by Dr. J. Brown, F. Crory, and Drs. F.S. Chapin, K. Van Cleve, and D. Hovland. The contents of this report are not to be used for advertising or promotional purposes. Citation of brand names does not constitute an official endorsement or approval of the use of such commercial products.

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## SUMMARY

Alyeska's restoration techniques largely reflect currently accepted practices in both arctic and subarctic regions (Johnson and Van Cleve 1976). Some instances of new approaches (seeds of native species, sod chips) were observed but these were limited in scope. Although numerous sites were successfully revegetated, some problems with revegetation were observed during construction. These included delayed seeding, inadequate erosion control during active construction, loss of topsoil due to improper site clearing, loss of fine-grained soils due to erosion, and limited reinvasion by native species.

Improved quality assurance and inspection programs during construction could have alleviated some of these problems. Once construction slowed, the revegetation program improved. Many erosion problems were either corrected or reduced by August 1978, and initial seeding programs were more than 90% completed on non-camp areas. However, problems such as buried topsoil could not be corrected.

Alyeska's Visual Impact Engineering Program has been initially very successful with a first-season survival percentage of 93%. In contrast, a 1977 program for establishing willow cuttings in disturbed areas and another program for sodding the trench of the fuel gas line between Pump Stations 1 and 4 had very limited success. Although it is too early to adequately evaluate Alyeska's 1978 willow cutting program, many improvements were implemented.

Terrain disturbances resulting from oil spills and snowpads have created some problems but few widespread impacts. As with revegetation, proper monitoring of construction alleviates much of the thermal and biological impact of these activities. For example, careful construction of the snowpad and backfilling of the fuel gas line ditch followed by early cleanup of the snowpad minimized damage to the underlying vegetation.

Restoration research by CRREL along the trans-Alaska pipeline shows promising results. Willow cuttings using *Salix pulchra*, and tundra sodding relying primarily upon tussock cottongrass (*Eriophorum vaginatum*) are feasible methods at certain sites for re-establishing native arctic vegetation. A native grass, blue-joint reedgrass, can provide a higher vegetative cover than Alyeska's seed mix (consisting primarily of exotic species) after less than two growing seasons.

The long-term success of restoration and vegetation recovery after terrain disturbances could not be adequately evaluated by the close of 1978. Questions such as the persistence of reseeded species can only be answered after two or more additional years of observations. Due to the low frequency of seed set in the Arctic, it will be several years more before an estimate of reinvasion rates of native species onto reseeded areas can be made.

# REVEGETATION AND SELECTED TERRAIN DISTURBANCES ALONG THE TRANS-ALASKA PIPELINE, 1975-1978

Lawrence A. Johnson

## INTRODUCTION

This report discusses selected terrain disturbances and the attempts at restoration techniques (including revegetation) as observed along the Trans-Alaska Pipeline System (TAPS) during the summers of 1975, 1976, 1977 and 1978. It is primarily observational since it was not possible to conduct detailed experimental investigations during the construction phase; however, quantitative data were collected when and where possible. The primary objective of the investigations was the evaluation of revegetation techniques as employed by the Alyeska Pipeline Service Company. This included determination of the relative success of grass species in seed mixes and the effect of revegetated areas upon reinvasion by native species. Observations of terrain disturbances are included in order to describe related impacts such as oil spills and construction and use of snowpads. Techniques which might mitigate some of these impacts are also discussed. Brown and Grave (1979) have reviewed most of the pertinent terrain disturbance literature associated with utility corridors in permafrost areas.

In addition, CRREL is conducting other research along the Yukon River-Prudhoe Bay Haul

Road which is closely related to pipeline revegetation. A report on that project contains descriptions and data on terrain, climate, vegetation, and soils north of the Yukon River (Brown and Berg 1980). Experiments at two locations along the arctic section of the Haul Road were established to test different techniques of restoration and results are discussed later in this report.

## REVEGETATION PROCEDURES

This report covers the second, third, and fourth years of revegetation observations by CRREL along the trans-Alaska Pipeline (Fig. 1). More than 78,500 ha of land was disturbed by construction of the pipeline including approximately 26,000 ha of workpad, 3,000 ha of access roads, 30,000 ha of material sites, and 1,700 ha of disposal sites (Pamplin 1979). Much of this disturbed land required revegetation. Observed revegetation areas included sections of the pipeline workpad, areas disturbed during construction of the fuel gas line from Pump Station 4 to Prudhoe Bay, road cuts along the Yukon River-Prudhoe Bay Haul Road, material sites, and disposal sites (Fig. 2). Observations for the

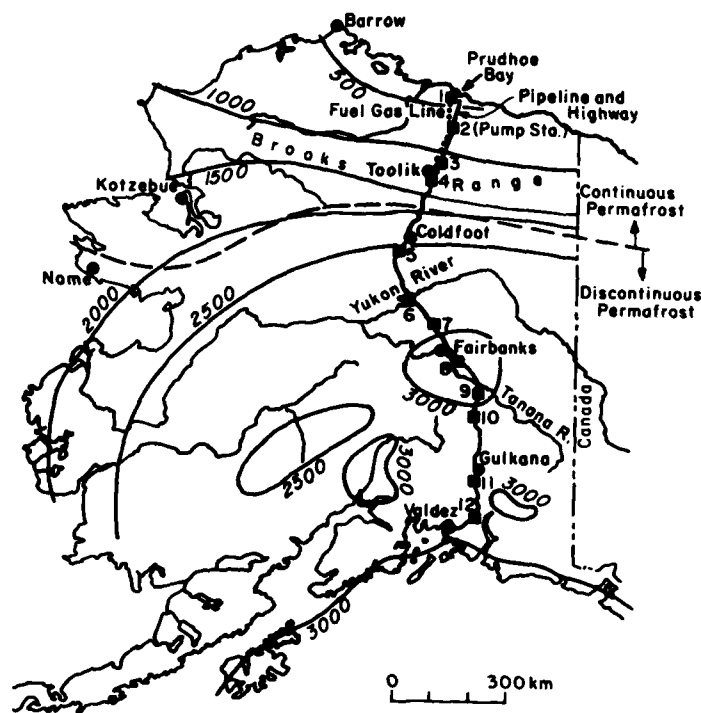


Figure 1. Map of Alaska showing route of trans-Alaska pipeline system, including pump stations, the boundary between the continuous and discontinuous permafrost zones, and the isotherms for degree days above freezing (degree days from Hartman and Johnson 1978).

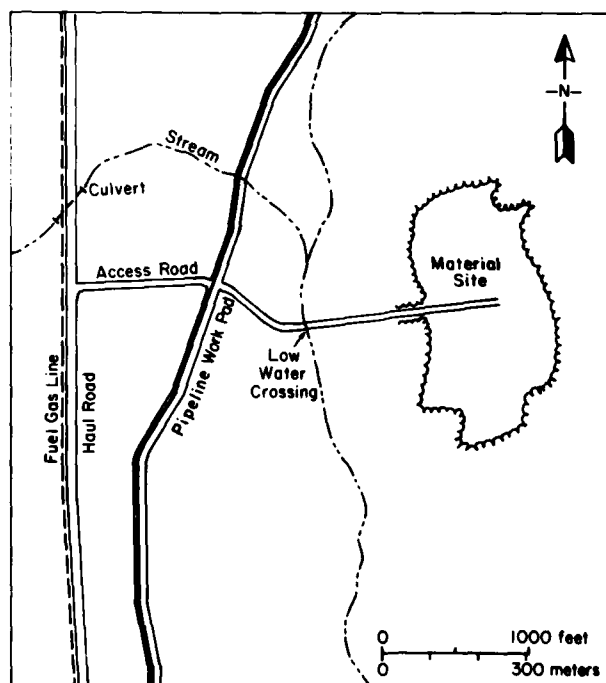


Figure 2. Idealized drawing showing major road and pipeline construction activities.

1975 summer construction season were reported previously (Johnson et al. 1977) and are briefly summarized here.

A number of terms are frequently used in reference to the reestablishment of plant cover. *Revegetation* refers to establishment of a cover of vegetation on a disturbed surface. *Rehabilitation* is a broader term that includes revegetation as well as other techniques to control erosion. Finally, *restoration* is a long-term process which returns the disturbed site to conditions similar to the original ones.

Research on revegetation and restoration within Alaska and northern Canada was limited until the late 1960's. At that time, and for a period of some four to five years, the Alyeska Pipeline Service Company undertook a revegetation research program (Johnson and Van Cleve 1976). Since commercial seed supplies of native species were few or nonexistent, the basic strategy which evolved was to select, from among existing commercial varieties of grasses, those which were best adapted to arctic and subarctic growing conditions. Lack of seed is a widespread problem which limits the use of the more desirable native species for revegetation (Sutton 1975). Field tests of varieties of grasses at selected locations along TAPS were used as the major basis for selecting both grasses and fertilizer levels (Mitchell and McKendrick, 1974a, 1974b, Van Cleve and Manthei 1972, 1973). In addition, extensive surface soil samples from the TAPS route were analyzed for nutrients. This information was then used to formulate fertilizer mixes which would provide both macro- and micro-nutrients for the Alyeska grass species.

Native species offer distinct advantages and are potentially very important for arctic and subarctic revegetation (Johnson and Van Cleve 1976, Bliss 1979). Two of these species, bluejoint reedgrass (*Calamagrostis canadensis*) and tall arcticgrass (*Arctagrostis latifolia*), were selected and placed into seed increase programs (Mitchell 1979). However, due to the long lead time required for commercial seed production of new varieties and the decision to rely primarily upon seeding for revegetation, Alyeska was, more or less, obligated to use introduced species of grasses (exotic species). Alternative methods, such as resodding with native vegetation (Younkin 1976), or fertilizing undisturbed tundra to provide increased sources of native seed\* were either not attempted or were considered

uneconomical or impractical. However, Alyeska did use native shrubs and trees in their willow cutting and visual impact engineering (VIE) programs.

The revegetation program used by Alyeska was an outcome of repeated proposals, counter-proposals and eventual approval as a result of discussions between Alyeska and state and federal regulatory agencies. As such, it represented a compromise between Alyeska design and regulatory concerns based largely upon environmental stipulations. Alyeska's primary reliance upon a seed mix of introduced grasses followed common practice in the Subarctic, although the exact species composition was unique to this project. However, the relative ease of this approach does not guarantee that it is an optimal solution (Webber and Ives 1978). Studies of a site disturbed in 1949 by early oil exploration in the Arctic have shown, depending upon soil moisture, ground ice content, and intensity of disturbance, that sites will naturally revegetate (Lawson et al. 1978). It may be preferable to let certain disturbances recover naturally or to facilitate reinvasion by native species in lieu of relying upon seeding programs.

Pipeline revegetation was employed primarily as a means of erosion control. However, Alyeska's stated long-term goal was restoration of all disturbed sites by permitting the reinvasion of native species (Lucas 1975). These two goals may conflict, at least in the short run. For example, the selection and use of well-adapted agronomic grass varieties in the revegetation seed mix could impede the reinvasion of native species onto a site once it has been successfully revegetated (Younkin 1976, Johnson 1978). Other goals for revegetation include promotion of a stable thermal regime, aesthetic considerations and production of wildlife habitat.

Alyeska's erosion control program was proposed in three phases. The initial phase, EC-1, involved seeding during the construction period and applied primarily to areas that were judged to pose erosion problems, although areas not to be disturbed again could also be seeded. During phase EC-2, or the cleanup period, permanent measures were to be implemented to rehabilitate construction sites. The third phase, EC-3, has involved erosion control maintenance needed to control unanticipated or recurring erosion problems until all sites are acceptably revegetated. EC-3 includes reseeding and refertilizing.

For construction purposes the route was divided into six sections or spreads (Fig. 3). Each

\*F S Chapin, University of Alaska, personnel communication 1978.



Construction section	Dormant seeding	Permanent seeding	Temporary seeding	No seeding
1,2,3	1 Oct - 10 May	10 May - 1 Aug	1 Aug - 1 Sept	1 Sept - 1 Oct
4	15 Sept - 1 June	1 June - 1 Aug	1 Aug - 15 Aug	15 Aug - 15 Sept
5	10 Sept - 1 June	1 June - 15 July	15 July - 1 Aug	1 Aug - 10 Sept
6	1 Sept - 1 June	1 June - 15 July	15 July - 1 Sept	

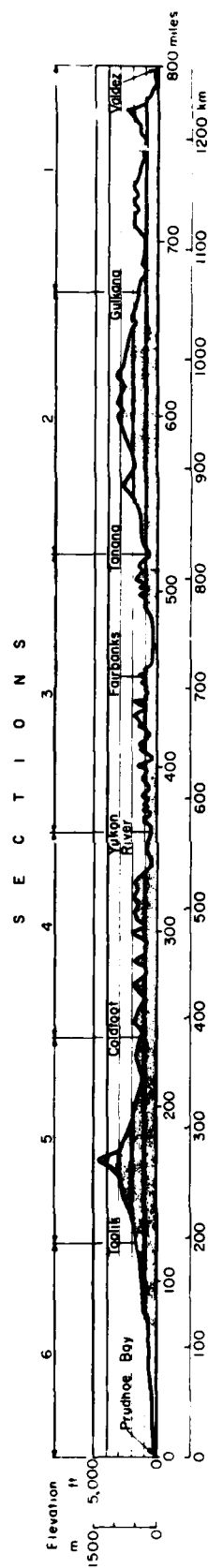


Figure 3. Topographic cross section of pipeline route showing seed mix and seeding schedules in the six construction sections (Lucas 1974, p. 10-11).

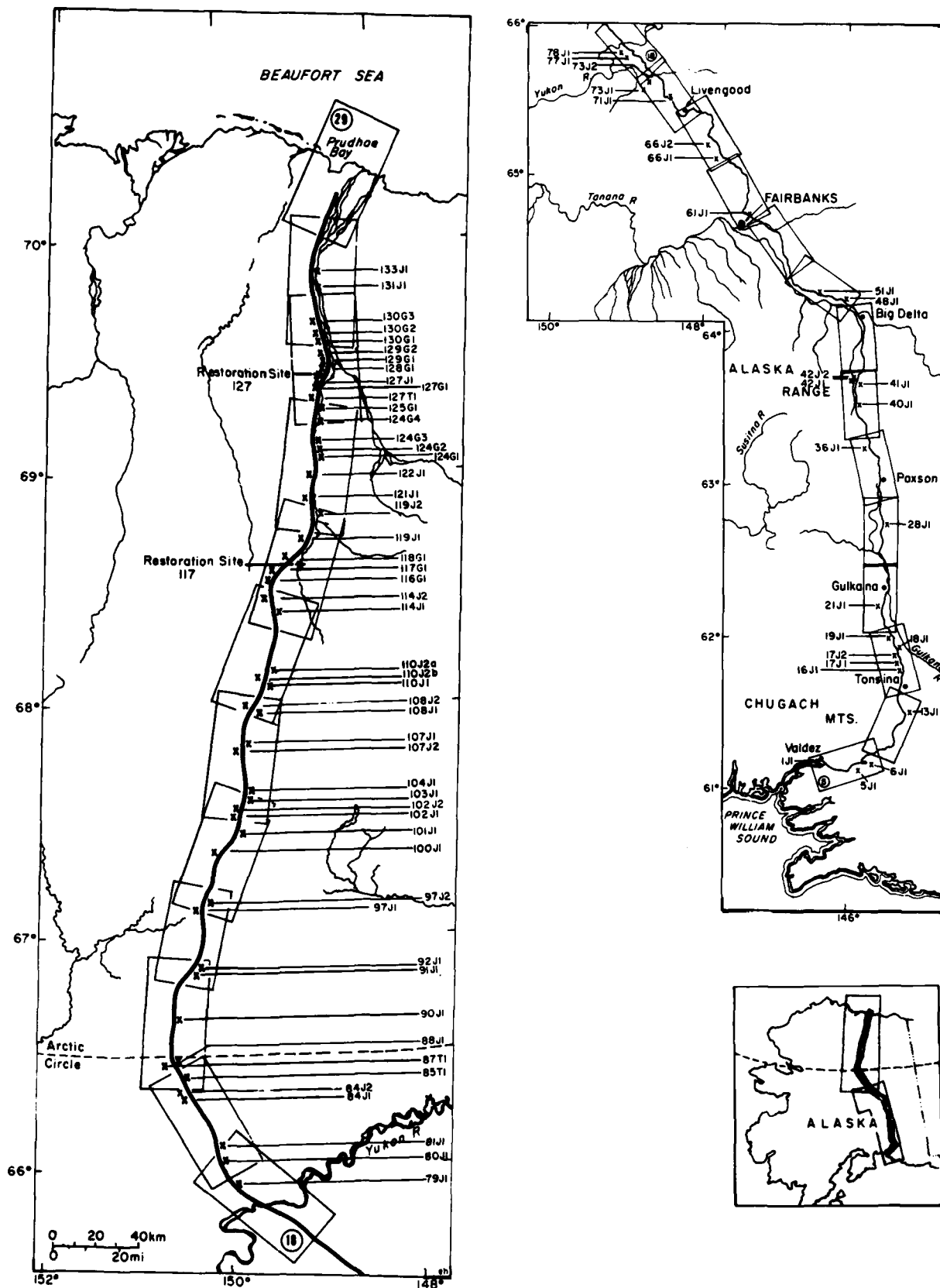


Figure 4. Location of fuel gas line (-G-), and CRREL revegetation (-J-), restoration and transect sites. Rectangular insert maps correspond to Wildlife Atlas maps (Hemming and Morehouse 1976).

**Table 1. Revised 1977 seed mixes and locations used (Lucas 1975, Hubbard 1980). Numbers in parentheses are the amounts used in the original 1975 mix in kg/ha.**

	Seed mix 1 North Slope Section 6 (Toolik to Prudhoe Bay)	Seed mix 2 Brooks Range Section 5 (Coldfoot to Toolik)	Seed mix 3 Interior Sections 1,3,4 (Coldfoot to Valdez, except Alpine)	Seed mix 4 Alpine Section 2 (Gulkana to Tanana River)
Arctared fescue ( <i>Festuca rubra</i> )	12.3 (16.5)	4.5 (16.5)		4.5 (11.1)
Nugget bluegrass ( <i>Poa pratensis</i> )	12.3 (11.1)	10.1 (11.1)	5.6 (0)	
Redtop ( <i>Agrostis alba</i> )	1.1 (5.5)	3.4 (5.5)		
Boreal red fescue ( <i>Festuca rubra</i> )	10.1 (5.5)	10.1 (5.5)	101.6 (4.4)	5.6 (4.4)
Durard hard sheep fescue ( <i>Festuca ovina</i> var <i>duriuscula</i> L.)		10.1 (0)	(4.4)	
Climax timothy ( <i>Phleum pratense</i> )		4.5 (5.5)	2.2 (0)	
Meadow foxtail ( <i>Alopecurus pratensis</i> )		11.2 (5.5)	6.7 (13.2)	12.3 (11.1)
Sydsport bluegrass ( <i>Poa pratensis</i> )			(3.3)	14.6 (5.5)
Manchar brome ( <i>Bromus inermis</i> )			10.1 (5.5)	2.2 (0)
Annual rye ( <i>Lolium multiflorum</i> )	14.6 (16.5)	13.4 (16.5)	7.8 (11.1)	7.8 (11.1)
Tall arcticgrass ( <i>Arctagrostis latifolia</i> )	1.1 (0)			
Total	51.5 (55.1)	67.3 (66.1)	43.6 (41.9)	47.0 (42.2)

section was further subdivided into alignment sheets which generally cover stretches slightly less than 10 km long. For example section 1 between Valdez and Gulkana includes alignment sheets 1-26 while the northernmost section between Toolik Camp and Prudhoe Bay includes alignment sheets 116-138 (Fig. 4). Alyeska utilized seed and fertilizer mixtures and application rates to accommodate the geographical and seasonal variations along the pipeline route. For this purpose four geographical zones were designated (Table 1).

During 1975, 1976, and portions of the 1977 growing season, Alyeska's revegetation program remained in phase EC-1. Modifications were made in design specifications but the basic erosion control program remained essentially unchanged. The seed mixes were altered during 1977 in order to reflect changing seed supplies and as part of the post-construction (EC-2) phase of revegetation (Table 1, Fig. 3). A consistent change in all mixes was a reduction in the amount of annual rye seed, although the rye was still a major component of the mix (16-25% by weight). The reduction in annual rye may reflect

higher germination rates due to better seedbed preparation, such as harrowing, after 1975, or reduced danger of erosion after construction was completed and thus less need for initial rapid growth. Concern that rye growth may be overly competitive with desired perennial growth was also an important consideration in its reduction in the seed mix.

A second change in the mix was the addition of a small amount of tall arcticgrass (*Arctagrostis latifolia*) seed in the North Slope mixture. Tall arcticgrass is one of the two native species from which Alyeska had seed commercially produced. Significantly, this represented the first step in the use of native species for revegetation along the trans-Alaska pipeline. Table 2 contains the composition of construction phase fertilizers, application rates, and the alignment sheets for the areas in which they were used. Fertilizers during the construction phase were coated with sulfur to enhance time release of nutrients. However, additional maintenance fertilizers used for refertilization were not coated and did not have micro-nutrients.

**Table 2. Fertilizer composition and application rates along the trans-Alaska pipeline (Lucas 1975).**

Nutrient elements (%)	Mixture		
	III*	IV*	V*
N	14.1	13.1	10.9
P <sub>2</sub> O <sub>5</sub>	7.1	14.6	15.1
K <sub>2</sub> O	21.3	17.5	14.5
S	5.0	1.3	5.2
Mg	4.2	4.4	3.6
Cu	0.49	0.36	0.36
Zn	0.57	0.58	0.48
B	0.14	0.14	0.12
Mo	0.0255	0.0262	0.0218
Application rate (kg/ha)	660	660	715

\*Employed on areas corresponding to the following alignment sheets:

III 1-5, 10, 11, 12, 2-39, 65-77 (Total 39)

IV 6-9, 12, 14-21, 40-64 (Total 38)

V 78-138 (Total 61)

The seeding schedule is shown on Figure 3. In order to account for seasonal variation, seeding schedules were devised that would minimize problems such as winterkill. Perennials seeded too late in the season would germinate and then be winterkilled because they would not have adequate time to become winterhardy prior to freezeup. Permanent seeding could only take place early in the growing season, followed successively by periods of temporary seeding, no seeding, and dormant seeding. Temporary seeding for rapid erosion control used only annual rye.

Seeding methods varied, with hydro-seeding (which generally mixes seed, water and mulch prior to spray application) being the most frequently used method during 1975-1977 (Fig. 5). Aerial seeding from fixed-wing aircraft was increasingly employed during late 1977 and 1978 on large areas such as the pipeline workpad (Fig. 6), while hand seeders, hydroseeders, ground-driven spreaders, air impeller spreaders and helicopters were used on smaller areas. Fertilizer was applied by similar methods except that specially modified sanding trucks, rather than hydroseeders, were also employed (Hubbard 1980). Fertilizer could be applied in combination with mulches but seeding was done separately from fertilizing. Alyeska planned to check both seed and fertilizer application distribution in the field against Rate Check Boards for quality control;

however, this procedure was probably never implemented.

Alyeska predesigned rehabilitation procedures and structures to control erosion. Allowance for local variation and unforeseen conditions was made by permitting Alyeska personnel to modify the standard procedures whenever field conditions necessitated them. An *Erosion Control Field Manual* was prepared to assist field engineers in determining necessary field changes. This manual contains erosion control procedures which provide guidance on such items as clearing construction sites, establishing disposal sites, controlling drainage and thermal erosion, application of mulches, techniques for revegetation, construction of channel liners, fish stream crossings and drainage ditches, and practices for maintenance of the restored areas.

Field implementation and record keeping were based on the rehabilitation plan and checklist, known as the "greensheet." The greensheets, which were prepared for a specific area or site, gave the procedures and estimates for materials, manpower, and equipment needed to complete the work. They were prepared for both physical reshaping and revegetation of disturbed sites (Johnson et al. 1977). Some problems were, however, presented by the use of greensheets. They did not always reflect the current status of a site, and it was difficult to document the entire history of a site unless all the sheets were available, since additional greensheets could be written for each separate action taken.

In addition to seed and fertilizer mixes, Alyeska specified a number of additional stabilization and revegetation procedures. These included the use of mulches such as straw and wood cellulose fiber, tackifiers, excelsior mats, jute netting, sprigging (the use of woody shrub cuttings), and the spreading of previously removed organic materials over disturbed areas. Shrubs and trees were transplanted as part of Alyeska's visual impact engineering (VIE) program, which involved planting of visual screens of trees and tall shrubs at pipeline crossings and other locations (e.g. material sites, etc.) visible from public roads.

Until 1977 there were generally two Alyeska rehabilitation personnel in each construction section who were responsible for implementing the erosion control plan along the pipeline right-of-way and in material and disposal sites. The number of personnel was reduced in 1977 and reduced further in 1978. The revegetation program at the pump stations and terminal facilities



*Figure 5. Hydroseeder with bales of wood cellulose fiber on trailer.*



*Figure 6. Aerial fertilization of pipeline workpad in the vicinity of Old Man (photograph by J. Brown, September 1976).*

**Table 3. Dates and locations of revegetation and construction observations (see Fig. 4 for locations of sites).**

Construction section	1975	1976	1977	1978
1	17 Jul, 19 Aug	29, 21 May, 2 Sep	20 Jun, 15 Sep	12-13 Sep
2	7, 10, 17 Jul, 20 Aug	21 Apr, 18-20 May, 1-2 Sep	29 Jun, 14-15 Sep	12-14 Sep
3	1 Jul, 29-30 Jul	18 May, 24 May, 19 Jun, 16 Aug	29 Jun, 6 Jul, 2 Sep	10 Jun, 16 Aug, 7, 8, 11 Sep
4	10, 11 Sep	25-26 May, 19-21 Jun, 16-17 Aug	6-7 Jul, 4-5 Aug	9-10 Jun, 15-15 Aug
5-6	26-29 Jul	3-4 Feb, 15-16 Feb, 3-5 Apr, 10-11 May, 25-27 May, 22-24 Jun, 17-21 Aug	10 Feb, 1 Apr, 7-8 Jun, 7-9 Jul, 4-6 Aug	7-9 Jun, 12-15 Aug

was handled by other Alyeska restoration engineers, although the guidelines were similar.

Construction of the pipeline was subject to extensive surveillance in order to ensure compliance with environmental safeguards as specified in the *Agreement and Grant of Right-of-Way* between Alyeska and the U.S. Department of the Interior (Mechanics Research Inc. 1977) and a similar agreement with the State of Alaska. There was a hierarchy of quality control and environmental surveillance over construction which began with contractor personnel overseen by Alyeska quality control employees. On federal land, final responsibility for surveillance was delegated to the Alaska Pipeline Office (APO) of the Department of the Interior while on state-owned land the State Pipeline Coordinator's Office (SPCO) had ultimate responsibility. Both APO and SPCO relied upon a joint federal-State of Alaska group known as the joint Fish and Wildlife Advisory Team for information on compliance with environmental regulations. In addition, both APO and SPCO had their own field monitors (Kavanagh 1977).

Special restoration programs were also initiated during 1977. In the spring of 1977 a willow cutting program was established in order to replace wildlife browse lost during construction. Also during the summer of 1977, the visual impact engineering program began. These two special programs are described later in this report. The majority of disturbed areas along the TAPS had been seeded by the close of 1977. EC-3, or the maintenance phase of revegetation, was begun on a very limited scale in 1978 and most areas were in EC-3 during 1979. By January 1980 nearly 45,000 ha was revegetated and initial revegetation was considered complete (Hubbard

1980). However, some special types of restoration work such as the willow cutting program were planned for 1979 and beyond.

### 1975-1978 CONSTRUCTION SEASONS

For this study, the author conducted field reconnaissance observations along the entire pipeline route during the summers of 1975, 1976, 1977 and 1978. In addition, numerous observations of the construction of the fuel gas line were made north of Pump Station 4 during the construction season in winter and spring of 1976 and a few observations were made during the winter of 1977. The dates and general locations of all observations are listed in Table 3. The number of completed areas dramatically increased as construction progressed until greater than 90% of the material sites, disposal sites, access roads, and portions of the workpad were regraded and revegetated by the end of the summer 1978. A number of access roads were permanently closed off with the placement of large berms across them after seeding was accomplished. Some camp pads, communication sites and other limited areas remain to be seeded.

In this study a number of revegetated sites were selected for permanent observations. Sites included those established in 1975 (Johnson et al. 1977) and new areas revegetated during 1976, 1977, or 1978. Several permanent revegetation sites were either partially or completely destroyed by construction and maintenance activities including pipe burial and regrading. All sites selected during 1975 are listed (App. A) and, if they were destroyed, this is so indicated in the photo caption of the appendices. Sites were se-

**Table 4. Observations at permanent revegetation sites along the trans-Alaska pipeline system.**

Site	Year seeded	1976 (1975)		1977		1978		Species setting seed*								
		Litter†	Live†	Max ht (cm)	Litter	Live	Max ht (cm)	Litter	Live	Max ht (cm)	Annual					
											Brome	Bluegrass	rye	Foxtail	Fescue	Timothy
a. Revegetation sites from Valdez to the Yukon River																
Road cuts																
73J1	early 1970's		8			7	130		5	150	d		a	d		c
78J1	unseeded															
Material sites																
17J2	1974		(9)	(95)		10	70		8	100			c	d	c,d	c
18J1	1976		7	65		10	130		5	135	c,d	c,d	b	d	c,d	c
28J1	1975	6	3 (1)	50 (5)		5	160		8	155		c	b	b,c,d	c,d	
36J1	1976		4	36		2(8 on edge)	100		2(5 on edge)	60			b,c	c	c,d	
71J1	1976					4	65		3	105	d	c,d		d	d	c
73J2	1975		Regraded										a			
Workpad																
5J1	1978								5	90			d			
6J1	1978								4	30			d			
13J1	1975, 1977	3 (hay)	8	100		Regraded			2	45			d	b,d		
16J1	1975		9 (6)	100 (25)		6	170		5	120	d			d		
40J1	1976		10	100		8	7	100	7	130			b	c,d		
61J1	1977								7	150	d	d		d		
66J1	1975		Site destroyed													
85J1	1976		1	8		7	100		2	95	d	c,d	d	c,d	c	
107J2	1976					4	8		6	111	d	b,c	d	d		
109J1	1977					2	8		6	87	d		d		d	
133J1	1977					3	15		5	15	d			d		
Workpad cuts																
19J1	1975	7	1 (6)	65		3			1	60			d		d	
42J1	1975		8 (10)	120 (8)		5	100		3	50		c		b,c	b,c	
42J2	1975					6	100		5	50		c		c,d	c,d	
48J1	1975	4	5 (9)	80 (90)		10	170		8	140		d		b,d	b,c,d	e
51J1	1975	10	1 (6)	25 (90)	10	3	100		3	60	d	d		d	d	c
102J1	1975		1	30		2	100		4	101		d	b,c	c,d	c,d	c
Disposal sites																
17J1	1975	2	9 (7)	140 (60)		9	150		10	150	c,d	c,d		b,d	c,d	c
66J2	1976					7	140		1	100		c	d	d		
77J1	1975	10	2	15		6			8	117	b	c	b	b,d	c,d	c
117G1	1976					4	6		4	96		d	b		d	
127J1	1976					4	20		4	80		c,d			c,d	
Other																
1J1	1975		7	100		7	100		8	170	d	b		d	c,d	c
21J1	1975, 1976	9	1 (2)	30(8)	7	2	100		4	115	c,d			c,d	c,d	
41J1	unseeded															
102J2	1976		8	65	10	4	100	8	2	153			b	c,d	d	
108J2	1975	10 (straw)	6	65	5 (straw)	7	130		7	90		c	c	b,c,d	d	
	probably		7	80		8	70		9	72		c	b	b,c,d	c,d	
114J2	1975		6 test plot	15		8	50	3	8	75						
129G1	1976		1 uncleared	3		5	15	5	8	35						
b. Revegetation sites along Yukon River-Prudhoe Bay Haul Road.																
Road cuts																
79J1	1975, 1976	1	6	—	5	7	100					c	b	c	c	
80J1	1975, 1976		10 lower	120		8	160		8	152	d	c,d	b	b,c,d	c	
			1 upper slope													
84J2			Destroyed by new construction													
88J1	1975, 1976	2	6	120	4	4 from 1975	150	5	2	130	d	c	b	b,c,d	c,d	
						8 from 1976										
90J1	1975	1	10	120		8	100	9	4	122	d	c	b	b,c,d	c,d	
92J1	1975		9	120		10	160	9	181		d	c	c	b,c,d		
97J1	1975, 1976	1	7	100		6	130	6	2	82	c,d		b	b,c		
97J2	1976					10	130	10	143					c,d	c,d	c
101J1	1975		5	90	4	8	130	8	7	77		c		b,c,d	c,d	
107J1	1975	9	9 (9)	70	9	9	120	9	8	81		c	b	b,c,d	c,d	
110J1	1975		1			2 (patchy)	60	3	50			c		c,d	d	
110J2a	1975		1	30		1	30	1	30					c	e	
110J2b	1975		4	65		3	75	2	73			d		b,c,d	c,d	
114J1	1975	1	6	80		1	60	2	60			b		d	b,c,d	
122J1	1975		4	80		8	80	9	80		c,d	b			c,d	
Material sites																
71J1	1976					4	65	3	105		d	c,d		d	d	c
73J2	1975		Regraded, site abandoned										a			
84J1	1976		4	30	4	3	60	2	2	30	d	c	b,c,d	c,d	c,d	
87J1	1977					5	100	2	5	135				d	d	
91J1	1974	1	3 (2)	65		2	100	2	120		c,d		b	b,d	b	
	probably															
103J1	1975, 1977	1	1	65		Regraded			3	78			b,d	b	b	d
104J1	1975	10	10	120		9	110	6	83					b,c,d	c,d	d
119J1	1975	9 (straw)	1	20	8 (straw)	2	30	2	85			c,d		b,c,d	c,d	
119J2	1976		1	45		4	40	1	35			c,d		c,d		
127J1	1975, 1976	1	5	65		trace	10	4	30			d		d		
Old trail sites																
81J1	1976					5	120	4	5	139		c		c,d	d	
100T1	1975, 1976	2	8	10	8	4	75	7	4	60		c	c		d	
108J1	1974		7	65		7	80	7	103		c	c,d	a		b,c,d	
	probably															

\* a = 1975; b = 1976; c = 1977; d = 1978.

† 1 = 1-10% cover; 2 = 11-20% cover; ... 10 = 91-100% cover.

— not observed.

lected to represent a variety of substrates, latitudinal and altitudinal locations, vegetation types, and categories of pipeline construction (e.g. workpad, road cuts, disposal sites, material sites). Sites are listed in order, from the southernmost (section 1) to the northernmost (section 6) and are identified by the alignment sheet number and the number within that alignment sheet (e.g. 79J2 identifies the second CRREL site from the south in alignment sheet 79, Fig. 4). Photographs of the late season growth (except where noted) are presented for all sites for all four years (App. B). Also, photographs of early season growth are included for comparison at certain sites.

At each study site photographs were taken at least once per growing season. In addition, estimates of percent cover of vegetation, established species, maximum height of vegetation, and presence of seed heads was recorded. Table 4 contains summaries of those observations. At a few sites biomass samples were taken annually (Table 5). The approach employed was to observe the entire length of the route, rather than selecting a few intensive study sites. This procedure resulted in a qualitative evaluation of the success of revegetation techniques through the several major climatic and vegetation zones. Problem sites are emphasized since they indicate the limits (geographical, bioclimatic, pedological, etc.) of the techniques which were employed.

There appeared to be adequate supplies and equipment available for revegetation from 1976 onward so that this did not present the problems it had during 1975 (Johnson et al. 1977). In fact, during 1976, some pipeline section personnel reseeded and refertilized extensive areas that had already been revegetated during 1975. This practice made it difficult to accurately assess second, third, and fourth year results and may have obscured long-term trends since reseeding and refertilizing influences vegetation response for an indeterminate length of time. Some reseeded sites had ample vegetation cover for erosion control as a result of the 1975 treatment; thus, repeated treatment was probably not necessary. It should also be noted that, in many cases where erosion problems were noted during 1975, corrective measures (such as reseeding or regrading) were taken during subsequent summers (App. B, site 21J1).

Observations from the 1975-1978 revegetation program can be summarized as follows:

1. *Topsoil.* In 1976 as during 1975, the use of

**Table 5. Biomass estimates (dry wgt g/m<sup>2</sup>) from permanent revegetation observation areas 1976-1978.**

Site	1976	1977	1978
	(Avg of 3 samples)		
19-1	33	48	13
21-1	5	39	43
51-1	5	106	59
77-1	16	156	160
92-1	743	412	641
103-1	65	Regraded	NA
114-2	68	104	180
127-2	88	Regraded	NA

topsoil and organic material was minimal. Topsoil was used at selected locations during 1977 and 1978. Attempts were made at many material sites to recover stockpiled topsoil. However, some topsoil was unrecoverable, because it had been buried or pushed downslope from material sites. The importance of topsoil and fine-grained subsoils was especially evident in the northern areas. Some material sites north of Toolik exhibited a rapid decrease in grass cover as one moved from the edge of the site, where organics and mineral soils were spread, to the middle of the site, which had no fine-grained soils on the surface. This confirmed the importance of organics and fines for water and nutrients (App. B, 119J2, 1978).

2. *Surface preparation.* Unlike the initial year (1975), during subsequent years much more attention seemed to be placed upon surface preparation. In many areas special harrowing equipment, such as a contour harrow (basically a large wire mesh with heavy wires protruding downward), was towed over the surface both before and after seeding (Fig. 7). Contour harrows were first used north of Toolik during 1976, and by 1978 they were in use in all construction sections. Harrowing appeared to result in greatly increased germination rates and subsequent increase in vegetative cover, probably primarily due to burial of the seed which increased available moisture (Fig. 8). Poor seedbed preparation was a major problem between Isabel Pass and Gulkana (construction section 2) where harrows were not used during 1975 and 1976 (Arctic Environmental Council 1977).

3. *Dormant seeding.* The dormant seeding during the winter of 1975-1976 seemed to produce vegetative cover at least as great as the summer seeding. However, dormant seeding in later years produced patchy grass cover in some





*Figure 7. Contour harrow used for seedbed preparation.*



*Figure 8. Harrowed ground in which seeds are buried, resulting in increased germination.*



Figure 9. Alder seedlings rapidly reinvading revegetated bank of disposal site, site 17J1, 12 September, 1978.

southern sections of the pipeline (sites 11J-13J) possibly due to inadequate seedbed preparation.

4. *River training structures.* Along the Koyukuk River a number of river training structures were constructed during 1976. These were mulched with straw and seeded, resulting in an excellent cover by the end of the initial growing season. Most of the cover, however, was produced by either barley or rye, both annuals. In 1977 living vegetative cover was greatly reduced and it continued to decline in 1978 (App. B, site 102J2, 1976, 1977, 1978).

5. *Variability in methods.* There seemed to be greater conformity in methods between construction sections during the 1976 and subsequent growing seasons. Generally areas were hydroseeded using seed, fertilizer, and wood fiber mulch. The amount of straw mulch and excelsior mesh used was much reduced in later years compared to the 1975 season. However, jute netting was used extensively on steep slopes in section 1 (site 5-14) during 1977 and 1978 (App. B, site 5J1, 1978).

6. *Native species.* A number of native species were observed on some of the revegetated areas. Fireweed was very abundant and the flowering heads of *Corydalis sempervirens* and *Senecio congestus* were prominent in many sites, especially in the Interior. Some shrubs, primarily

alder (*Alnus crispa*) and willow (*Salix* sp.), entered revegetated areas by seed. Extensive invasion by native species was observed only at sites south of the Alaska Range. At one site, alder and some willows rapidly established an extensive cover on a revegetated area (Fig. 9). Finally, in at least some cases, native grasses (bluejoint reedgrass south of Atigun Pass, tall arcticgrass north of Atigun Pass) were flowering more profusely adjacent to the workpad and other disturbances than in undisturbed areas.

It was observed that physical disturbances, such as construction of the workpad, change a number of soil conditions by affecting drainage and thermal regime. As a result flowering could presumably be enhanced by increasing one or more of the following: moisture, nutrients, and soil temperature.

7. *Dominant species.* Whereas annual rye was the dominant species on almost all sites during 1975, meadow foxtail was the dominant species on most sites south of Toolik during 1976 (App. B, site 88J1, 1976). In 1977 and especially 1978, foxtail was still dominant on many sites but timothy, bluegrass, and fescue were major components, if not dominant, on at least some sites. Foxtail frequently produced a high density of seed heads on favorable sites, even if other species did not flower (Table 4). In areas which



Figure 10. Test plot for tall arcticgrass seeding, 5 August 1977.

were reseeded, annual rye sometimes was dominant over foxtail (see Table 4, site 97J1, 1976). Fescue was the dominant perennial species in section 6 where foxtail was not used.

8. *Test plots.* Alyeska established some test plots in 1976 to evaluate commercially produced seed of the native species, tall arcticgrass, *Arctagrostis latifolia*. These plots produced abundant seed heads and a good cover (greater than 80% by the end of 1977, Fig. 10).

9. *Application rates.* Despite the extensive preparation of field manuals by Alyeska, work crews did not always strictly follow the stated methods. Seeding and fertilizer applications occasionally varied due to inadequate instructions to workers or to lack of fertilizer and seed rate check boards. Clods of fertilizer were observed at a number of locations during 1977 and 1978, probably because the fertilizer had absorbed water and hardened during several years of storage (Fig. 11).

10. *Atigun Pass.* This area poses perhaps the ultimate challenge to biological methods of erosion control along the entire pipeline route. The cold, abbreviated growing season conditions (Brown and Berg 1980) allow only minimal plant growth. Rocky soils with a low percentage of fines (see comment 16 below) further limit growth. The workpad in this area was seeded during 1977 and by the end of 1978 there was

40% live cover on the northern side of the Pass. However, the cover was patchy and some areas had been regraded due to settlement over the pipe (Fig. 12).

11. *Arctic.* Reduced growth was documented north of the Brooks Range during 1976, but the contrast with other areas was less than during 1975. Sites were seeded earlier in the season during 1976-1978 and, of course, previously seeded sites already had some established vegetation. Maximum height of the vegetation was still less than in southern areas but percentage cover was comparable on at least some sites (App. B, site 133J1, 1977 and Table 4).

12. *Sukakpak Mountain* (App. B, site 103J1). Scenic considerations mandated that special measures be taken at this location, which had been temporarily used as a material site. Sukakpak was the only site observed where large amounts of fine-grained soils and topsoils were transported to the location and spread over it to create an enhanced seedbed. Then, in addition to the normal seeding and fertilizing, transplants and nursery-raised seedlings of white spruce were planted along the access road. The appearance of the area was markedly improved by August 1978, the end of the first full growing season (Fig. 13). Grass growth was noticeably better near the base of tree transplants, probably due to improved moisture conditions



*Figure 11. Clumped distribution of fertilizer, note increased growth around edges of fertilizer clod. 14 August 1978.*



*Figure 12. Reseeded workpad on north side of Atigun Pass (14 August 1978)*



*Figure 13. MS 103J1 viewed from road, 15 August 1978. Transplanted spruce are seen in the foreground on an access road.*



*Figure 14. Clumped distribution of grass around tree transplants at the base of Sukakpak Mountain.*



Figure 15. Caribou grazing on revegetated workpad, 14 August 1978.

associated with the fine-grained soils around the tree roots (Fig. 14).

13. *Animal grazing.* Various populations of native mammals and birds have been observed grazing upon revegetated areas. They included microtines at numerous locations, caribou north of Toolik (Fig. 15) and especially at site 127J1, dall sheep along the workpad near Galbraith Camp, bison at AS 42 and moose in the Interior (Fig. 16). Birds such as ptarmigan and migratory waterfowl extensively grazed on revegetated areas north of Toolik. Presumably these animals were attracted by factors such as the delayed senescence of introduced species and the higher nutrient content of vegetation within the fertilized areas.

14. *Weed species.* Whenever seed supplies are produced in one location for use in a distant environment, the introduction of some seeds of exotic weeds in the mix is inevitable. Such weeds are opportunists that were not previously present in the area (Brown and Berg 1980, Kubanis 1980, Johnson and Kubanis 1980). This problem is more pronounced in a massive construction project such as TAPS which requires large seed supplies and extends over 800 miles. Grass seed for the Alyeska mix came from a number of locations, including Oregon, Washington, Alaska, and the Peace River Valley in Alberta. Although it was tested to meet germination and purity requirements, even certified seed may contain a

low percentage of weed seeds. In addition, certain mulches, such as straw, may provide another entry point for the introduction of weed species. One of the most frequently observed weed species along TAPS was pigweed (*Chenopodium album*), which was frequently introduced in the straw mulch and may also have been present in the seed mix. The only weedy grass species that was observed by the author was *Bromus tectorum* which was found at several sites in construction sections 2 and 4 during 1977 and in construction section 5 in 1978. Numerous other species of weeds have been reported (Brown 1978, Kubanis, 1980, Johnson and Kubanis 1980).

15. *Scheduling.* During 1975 (and also during 1976-1978 in certain sections) seeding was not completed on schedule. This meant that erodible areas were left unseeded for longer periods than desired and that introduction of an adequate vegetative cover was delayed.

16. *Temporary erosion control.* In at least several instances inadequate erosion control practices during construction contributed to the loss of valuable fine-grained soils and consequent siltation of nearby water courses. Proper use of engineering measures such as water bars and retaining dikes could have reduced or alleviated these problems (Williams 1976). During excavation of the oil pipeline ditch on the north side of Atigun Pass in June 1977, erosion was par-



*Figure 16. Revegetated area heavily grazed by moose during CRREL observation, 10 September 1975.*

ticularly severe. The loss of fine-grained material in this very severe alpine environment will retard successful revegetation and restoration (Brown et al. 1978).

Temporary erosion control was a recurring problem along the trans-Alaska pipeline. This problem could have been reduced, along with other environmental problems, by an improved quality assurance program (Carson and Milke 1976, Zemansky 1976, Morehouse et al. 1978).

During 1978 the Alaska Pipeline Office (1977) formulated criteria for determining the success of restoration of disturbed sites along TAPS. Depending upon the location and the soil type existing at a site, minimum requirements for vegetation cover were specified. No revegetation is required on those sites that 1) have a covering of undecomposed plant matter, 2) will have continued disturbances for pipeline operations or maintenance such as traffic lanes, 3) are located in active floodplains, or 4) possess inadequate fines (silts, and clays) in the soils. Sites with less than 15% silt and clay sized particles in the upper 15 cm of soil must have a 30% cover of vegetation over 80% of the area. More than 50% plant cover over 80% of the area is required on sites with greater than 15% fines. In addition,

plants must show adequate vigor so that nutrient deficiencies or physiological stress is not apparent. If sites do not meet these requirements, then remedial measures such as reseeding are mandated. Some sites were evaluated by APO personnel during 1978 on the basis of these criteria. The sites that fulfilled the criteria were then returned to the Bureau of Land Management, relieving Alyeska of future liability.

Alyeska's revegetation program generally improved from 1975 to 1978 in terms of seedbed preparation, scheduling, and availability of supplies and equipment. In large part this was due to lessening of construction activity so that environmental matters were given higher priority (Zemansky 1976). But experience gained by Alyeska personnel also contributed to improvements in the program.

#### **WILLOW CUTTING PROGRAMS**

In order to meet Federal stipulations requiring 1) restoration of wildlife habitat and browse lost during construction of the trans-Alaska pipeline, 2) inducement of large mammals toward big game crossings, and 3) restoration of disturbed



Figure 17. Storage of willow whips at Dietrich Camp following melting of the snow (8 June 1977).

sites to near-natural conditions, Alyeska undertook a major transplant program of feltleaf willow (*Salix alaxensis*) cuttings during the 1977 construction season in order to replace this browse. The plan was for cuttings of feltleaf willow to be first rooted indoors and then planted on 2-m centers over some 365 ha of disturbed areas. These areas were primarily material sites and sections of the oil pipeline workpad.

Willows were collected from a number of locations in the general vicinity of the pipeline route, mainly in river bottom areas. Collection sites included areas near Slope Mountain (site 119J1), the Toolik and Atigun rivers, Galbraith Camp, and several other locations including some south of the Brooks Range. However, less than 20% of the more than 1 million cuttings were collected from such southern sites. Willows were collected according to a set of guidelines designed to maximize success while minimizing the impact of the collections upon existing willow communities. Guidelines included a minimum diameter (1.25 cm) and a maximum cutting rate per shrub and per stand. Most collections were made in May and all collections stopped as of 5 June 1977. Higher success was expected with dormant (hardwood) cuttings than with growing cuttings, but collections began so late that some willows had already begun flowering when collected.

In the field, willow stems were initially cut into 1.2- to 1.5-m long whips. Smaller branches were trimmed off before packaging the whips in burlap bags for transport to Dietrich Camp. At Dietrich the whips were stored outside in snowbanks until they could be processed. After snowmelt, the whips were watered daily to prevent desiccation while they remained outside (Fig. 17). The whips were subsequently cut into 15- to 22.5-cm lengths (20 cm average) on a band saw. The thin diameter tips (1976 growth) were generally discarded so that most cuttings were 2 to 4 years old. Except for a small number of early cuttings the proximal (basal) end of each cutting was dipped in a preparation of 4000–5000 ppm of indole butyric acid (IBA) to stimulate rooting and in a fungicide. The distal (top) end of the cuttings was coated with a colored paraffin layer to reduce water losses and to identify (by color) the source location of the cuttings. Cuttings were then placed in pots of compressed peat (Jiffy 7) which had been soaked in fertilizer solution until they had swelled to about 5 cm in height.

Groups of cuttings were held in plastic trays and these were placed on tiers of shelves inside a modified warehouse (Fig. 18). The temperature in the warehouse was kept at 21–23°C and the relative humidity was maintained close to 80%. Cuttings were sprayed regularly with water until





*Figure 18. Willow cuttings in warehouse after being trimmed, coated, and potted (8 June 1977).*

a mist system was installed to keep the cuttings moist as well as to maintain a high humidity.

Additional lighting was installed in early June in order to increase illumination. At that time some cuttings had already been in the warehouse for three weeks. Rooting success appeared to be very high and some roots extended beyond the outer edge of the Jiffy pots. One source estimated that between 80-90% of the cuttings in the program rooted (Zasada et al. 1977).

Some problems were already apparent in early June 1977. Many of the willow leaves, especially on the lower shelves which were shielded from the overhead lighting, were severely chlorotic. Cuttings frequently had root growth along the entire length of the stem, presumably due at least in part to the high humidity. Also, there was evidence of fungus growth on some of the stems. Fungal spores may have originated in the peat pots, but high humidity accelerated fungal growth.

Following root initiation, cuttings were to be hardened off by gradually increasing the photo-

period and by lowering temperatures in the warehouse at least two weeks prior to planting. Originally scheduled to be accomplished from late June to 31 July, planting continued into early August (Fig. 19). Augers were to be used to make holes in the gravel for planting the cuttings on the 2-m centers. However, augers were not feasible for many of the gravelly or bouldery sites. Instead handpicks were used for planting. The cuttings in the peat pots were placed in the holes and then were covered over with the mineral soil to the maximum extent possible. Planting crews had a difficult time digging holes in some of the highly compacted gravels and tills.

At one site (MS 111-1A), cuttings were buried only 2 to 3 cm, at most, based upon an average total length of 20 cm. Many cuttings had the Jiffy pot exposed above the ground. A survey of 200 cuttings revealed that 46% had 15 cm or more of stem aboveground, 46% had 10-15 cm aboveground, while only 8% had less than 10 cm above ground. Preliminary studies had already indicated that cutting success is lessened by

**Table 6. Survival of percentage of willow (*Salix alaxensis*) cuttings in the first summer of planting (6 August 1977).**

Site	Substrate	% Survival
Workpad south of Chandalar Camp	Gravel with numerous fines	4
MS 112-0	Gravel, large cobbles	0
MS 113-2	Gravel with organics, mesic	5
AS 120 disposal site	Mineral soil with organics dry	3
MS 121-3	Silts and organics, gravel	3
MS 122-3	Gravel with a few fines	0

lengths greater than 2 to 3 cm above ground (Zasada et al. 1977). Furthermore, the more shallowly placed cuttings were in a drier soil environment.

In early August 1977, a survey of six sites was made in order to assess the survival rate of the cuttings prior to winter. At that time a few cuttings were still being planted but the stock remaining at Dietrich Camp was very limited and in noticeably poor condition. The average survival rate (based upon unwilted leaves present) at the six sites was 2.5% (Table 6).

A resurvey of the same sites in mid-August 1978 showed that less than 1% of the cuttings had successfully overwintered. Other planting programs with unrooted feltleaf willow cuttings have had very high success rates (88-96%) after three years in the Arctic (Younkin 1976).

During 1978, Alyeska initiated two programs using unrooted cuttings. Whips were collected, as in 1977, during the early spring prior to snowmelt and were stored in freezers until ready to be planted. The whips were cut into 8 to 9-cm lengths and some of them were planted as unrooted cuttings by Alyeska field crews in a few selected material sites near Pump Stations 3 and 4. The remaining cuttings were used in a research program conducted by the University of Alaska for Alyeska. Success rates in mid-August 1978 were much greater for the unrooted cuttings than they had been for the rooted cuttings in 1977. For example, based upon the author's field observations, the cuttings used by Alyeska for their limited 1978 program had a 67% survival rate in mid-August 1978 (Fig. 20). Most of the cuttings appeared to be vigorous and healthy.

#### **VISUAL IMPACT ENGINEERING (VIE)**

In the latter part of the summer 1977 and con-

tinuing through the 1978 growing season, Alyeska began to transplant trees and shrubs at pipeline-road intersections and at a few material sites as part of its VIE program. Species used varied depending upon the local vegetation. They included birch (*Betula papyrifera*) (Fig. 21), white and black spruce (*Picea glauca* and *P. mariana* respectively) (Fig. 22), willow (*Salix* spp.) (Fig. 23), aspen (*Populus tremuloides*), and alder (*Alnus crispa*).

Plants were generally taken from nearby undisturbed areas. In most cases plants were removed and planted by machine so that a ball of soil was taken along with the tree or shrub. A mulch such as hay or woodchips was often placed at the base of the transplant.

The VIE program has been important for ecological as well as aesthetic considerations. As previously mentioned, the fine-grained soils, mulch, and microclimate associated with the transplanted shrubs and trees can create very favorable microsites for vegetation growth on otherwise poor growing sites (Fig. 14). Furthermore, the transplants act as islands of seed dispersal onto the sites for the transplanted woody species. By decreasing the distance that seeds have to travel to cover the entire site the transplants can accelerate the re-establishment of native woody species.

Transplant survival generally appeared very high. In August and September 1978, a survey of 12 VIE sites (two material sites, AS 66-2 and 103J1; 8 pipeline crossings, AS 13, 21, 39, 41, 61, 70, 85, 92 and two workpads, AS 5 and 6) indicated better than a 93% average survival rate. The lowest observed survival was 88% for birch at one site. However, many of the transplants had not overwintered and increased mortality may occur in subsequent years.



*Figure 19. Planted cutting showing wilted, chlorotic leaves (5 August 1979).*



*Figure 20. Unrooted willow cutting near Pump Station 4 (5 August 1978).*



*Figure 21. Birch transplants (VIE) near Old Man (4 August 1977).*



*Figure 22. Spruce transplants (VIE) near Prospect, AS 96, (15 August 1978).*



*Figure 23. Spruce and willow transplants (VIE) near Donnelly Dome (AS41, 14 September 1977).*

#### **SELECTED TERRAIN DISTURBANCES**

In addition to the more than 78,500 ha of disturbed land directly and indirectly associated with pipeline construction, other areas of previously undisturbed vegetation have been affected. These include areas subjected to impacts such as road dust and impoundments (Brown and Berg 1980), snowpads (Johnson and Collins 1980), and oil spills (Johnson et al. 1980). The next section of the report discusses some of these terrain disturbances and, in some cases, revegetation or restoration following the disturbance.

##### **Fuel gas line and snowpads**

During the 1975-76 winter, Alyeska initiated construction of a 25-cm-diameter fuel gas line from Pump Station 1 to Pump Station 4 (Fig. 1), a distance of about 230 km. The purpose of the line was to provide fuel for the turbines powering pumps at Pump Stations 2, 3 and 4. Although the installation of this small diameter pipeline was originally scheduled to be completed during one winter season, unanticipated construction problems necessitated a second winter (1976-77) for completion of the pipeline (Bock 1979, Keyes 1976, Carson and Milke 1976). CRREL personnel

observed construction of the fuel gas line several times during the two winters as well as the cleanup and erosion control methods and revegetation employed during the summers of 1976, 1977 and 1978. The results of the subsequent revegetation observations provide valuable information on methods to control erosion, or associated revegetation problems, and the effects of snowpad construction upon vegetation and the underlying tundra. Engineering considerations of the snowpad construction are described elsewhere (Johnson and Collins 1980).

The entire fuel gas line, except for short sections along the oil pipeline workpad and at stream crossings, is generally situated within 1.2 m of the downslope side of the Haul Road. At stream crossings the line is offset from the road. Snowpads were used for construction of all portions of the line except those on the oil pipeline workpad (Fig. 24). Snow was first collected alongside the road by using a Gradall machine to collect snow from the road shoulder into berms on the edge of the road (Fig. 25). These berms served to catch additional blowing snow. When adequate snow was collected, the berms were leveled by blading and by bulldozers dragging metal net or steel beams for packing the snowpad (Fig. 26 and 27).

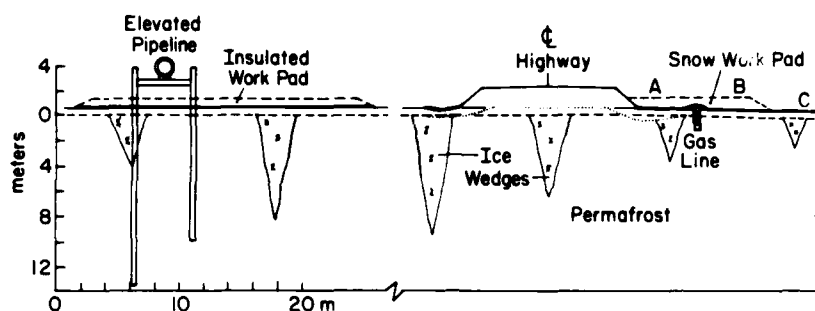


Figure 24. Schematic drawing of winter construction of fuel gas line through snowpad adjacent to road. A, B, and C indicate positions of thaw measurements.



Figure 25. Gradall machine making berm beside road shoulders in order to catch additional snow used for snowpad construction, (15 February 1976).

Once the snowpad was completed, trenching operations began, using several different methods and equipment. Initially, a small snowblower removed most of the snowpad over the ditch locations (Fig. 28). Then either a Roc-Saw or a Barber Greene trencher began excavation. In fine-grained soils, Roc-Saws trenched a 46-cm-wide by approximately 1.8-m-deep trench in a single pass, conveying the pulverized spoil to the edge of the road (Fig. 29 and 30). The Barber

Greene trencher (Fig. 31) cut a wider (60 cm), slightly shallower trench, and the 8- to 15-cm diam pieces of spoil were moved to the side of the road by a conveyor system. On certain sections the two machines were used in tandem, in which case the Barber Greene trencher made an initial pass to remove the surface sod and the upper 0.3 m or so of frozen soil, and the Roc-Saw completed the trench on a second, deeper pass. In this case the spoil was either deposited on the



*Figure 26. Bulldozer blading snowberm to form base of snowpad, (14 February 1976).*



*Figure 27. Bulldozer packing snowpad by dragging steel beams, 4 April 1976.*

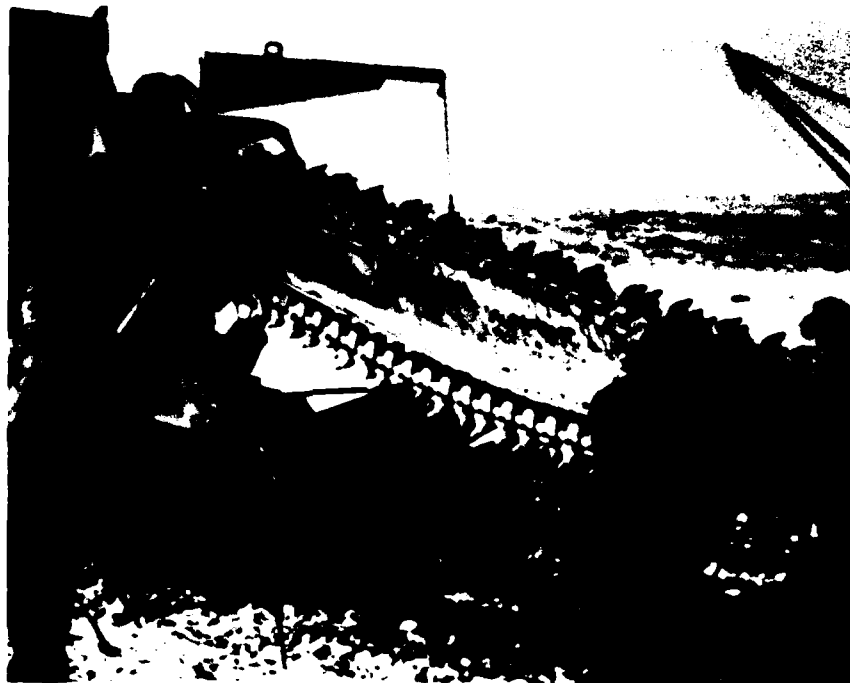


*Figure 28. Snowblower clearing fuel gas line ditch prior to excavation, 3 February 1976.*



*Figure 29. Roc-Saw trenching fuel gas line ditch through snowpad. Spoil was deposited on the road shoulder (photograph by P. Johnson).*





*Figure 30. View of cutting edge of the Roc-Saw trencher mounted on D-9 tractor, 5 April 1976.*



*Figure 31. Barber Greene trencher used for ditching fuel gas line (photograph by J. Brown).*



*Figure 32. Close-up of trench excavated with a Roc-Saw. Note spoil over the snowpad.*

road shoulder by the conveyor system or more frequently deposited directly on the snowpad. Although originally prohibited by technical specifications, Alyeska received approval from APO to place spoil on the snowpad in February 1976 (Carson and Milke 1976). The spoil was subsequently graded into piles and hauled away to disposal sites. Unfortunately this method left some spoil on the snowpad (Fig. 32), which induced melt during the late spring and deterioration of the snowpad (Johnson and Collins 1980) as well as contributing to adverse impact upon the underlying vegetation.

Trenching began during winter 1975-76 in the vicinity of Franklin Bluffs and between Galbraith and Toolik camps (Fig. 1). In the latter area, the trenching operation quickly encountered problems primarily due to the bouldery glacial till and also due to blowing snow which rapidly filled the open trench. In the bouldery sections between Galbraith Lake and Slope Mountain, it was necessary to blast and backhoe most of the trench. After blasting, backhoes were used to clean out the ditch which was frequently up to 1.8 m wide (Fig. 33). Between Galbraith and Toolik Lakes, large explosive charges were used as evidenced by the large amount and pieces of debris, up to 25 cm or more in diameter, which were blown off to either side of the trench to dis-

tances up to 30 m or more (Carson and Milke 1976).

Prior to trenching, surface organics which contained living vegetative parts (and which would increase the moisture holding capacity of the seedbed) were to be removed, stored and later used for revegetation (Carson and Milke 1976). Where practical, sod chips were gathered by the Barber Greene trencher which made the initial shallow pass before the Roc-Saw completed the trench as described above. The quality of this operation varied with the operator. Some operators were able to consistently remove the organic layer with just a small amount of mineral soil, whereas others cut more deeply so that the organics formed only a small percentage of the "sod chips." This dilution of the sod by the mineral soil reduced the potential for regrowth. Chips were usually placed on the snowpad, graded into piles, and then were trucked to irregularly-spaced disposal sites for temporary storage. Sod stockpiles were up to 80% snow by volume (Carson and Milke 1976).

Ideally, chips should have been immediately collected in a container to avoid mixing with the snow. These materials could then have been returned to the trench in the same general area so as to correspond with the original soil and vegetation conditions. In addition to mixing snow



Figure 33. View of blasted fuel gas line trench after excavation by a backhoe.

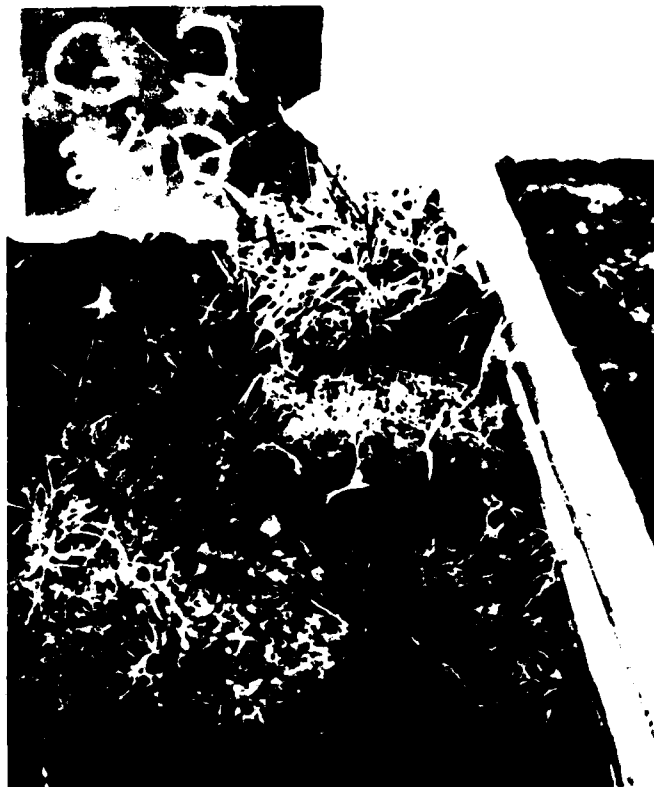
into the chips, the handling also broke the chips up so that the average chip size was relatively small (5 to 8 cm in diameter). Chip size is important since it appears to have a direct bearing on the viability of the vegetative propagules in the organic matter. The author conducted studies on sod randomly collected from an experimental ripper test in winter 1975-76 and from the Barber Greene trencher operation in order to estimate the potential success of resodding with these chips. The sod was placed in a laboratory chamber at approximately 24°C under fluorescent lighting and watered daily. Live vegetative cover from the larger sod chips (up to 46-cm diam) averaged 10-50% after three weeks, although it did vary according to the size of the chip and species composition (Fig. 34). Larger chips generally had greater growth. The sedges, *Carex bigelowii* and *Eriophorum vaginatum*, showed rapid growth while the shrubs, *Cassiope tetragona* and *Arctostaphylos rubra*, as well as the mosses and lichens recovered more slowly. The smaller sod chips from the Barber Greene trencher were more prone to desiccation, and hence vegetative cover was less. Roc-Saw spoil had minimal regrowth and vegetation cover was less than 1%. Canadian researchers\* have exper-

imented with the use of tundra sod and have reported similar results.

After trenching was completed, gravel was placed in the trench for bedding, the pipe was placed in the trench, and the trench backfilled with additional gravel. Gravel for backfill initially was hauled by dump truck or belly loader to the trench, dumped onto the snowpad, and then graded into the trench by a bulldozer (Fig. 35 and 36). This method left significant quantities of gravel on the snowpad.

Later in the spring of 1976 and during winter 1976-77, a cleaner method was developed. The gravel was dumped onto the edge of the roadside, graded into a berm, rocks were removed by hand, and then a "wooly-worm," consisting of an auger for intake and a long chute for placement, was used to put the gravel directly into the ditch (Fig. 37). In order to prevent thaw over the pipe and maintain pipe and soil at the same temperatures, strips of rigid insulation were placed below ground level in the trench at a depth of approximately 30 cm (Fig. 38). The insulation was covered by enough gravel to form a small berm. Due to the dirty snowpad and the uneven thickness of the snow, it was frequently difficult to detect the soil surface, so that insulation at times was mistakenly placed either above or at improper depth below the ground surface. In

\*W. Younkin, R.M. Hardy and Associates, personal communication, 1978.



*Figure 34. Sod obtained from the trial ripper test growing in the laboratory.*



*Figure 35. Gravel for backfilling the fuel gas line trench being dumped onto snowpad prior to fill operation (photograph by J. Brown).*



*Figure 36. Bulldozer grading gravel into the fuel gas line trench, 10 May 1976. Note broken insulation and snowfencing previously used for protecting the pipe during blasting and other debris on left side of photograph.*



*Figure 37. "Wooly worm" backfilling fuel gas line trench with gravel from road shoulder (photograph by P. Johnson).*

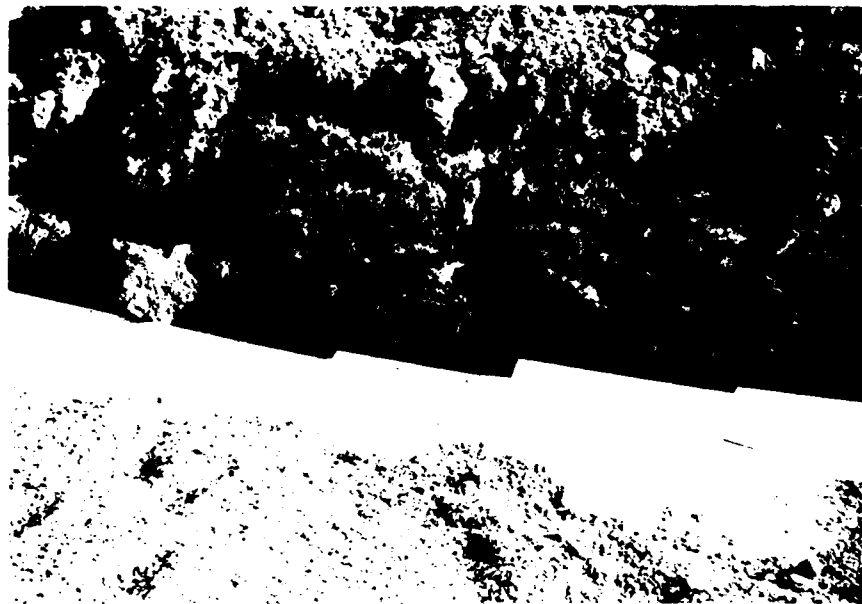


Figure 38. Styrofoam insulation placed in fuel gas line trench below ground level (photograph by J. Brown).

specified areas, either sod chips or Roc-Saw spoil was placed over the gravel berm before thawing occurred.

Cleanup operations to remove debris from the pad were of several types. Along the blasted sections of trench, groups of hand laborers picked up the broken snow fence and insulation fragments which had been used to protect the welded pipe during blasting. The snowpad was scraped by belly loaders in order to remove most of the spoil and gravel. Work continued on the fuel gas line into late spring 1976. The snowpad, as it softened, became increasingly contaminated with both spoil from the trench and gravel from backfill. For example, debris 15 to 25 cm in thickness was frequently seen on the snowpad right-of-way in May. Later in the spring after meltoff, backhoes and cranes with large buckets operated from the road to scrape debris from the tundra (Fig. 39 and 40). As the cleanup continued into July or August, these layers of gravel and spoil were reduced to scattered patches less than 3 cm in depth in most instances. However, the cleanup operations also removed the sod chips from the surface of the ditch and often sheared off the tops of *Eriophorum vaginatum* tussocks and other erect vegetation.

Hydraulic erosion became a serious problem along the gas line route during spring breakup in

1976. Water filled some sections of the ditch which had not been backfilled. Frequently water from culverts washed gravel out of the ditch and in some places water became channelized over the trench (Fig. 41). In order to alleviate these problems, various corrective measures were taken. Insulation was placed beneath the true ground surface and the ditches were backfilled above ground level by the "wooly worm" technique. Half culverts or lined channels were extended across the trench from existing culverts (Fig. 42 and 43) and problem areas were sandbagged to deter water from running down and over the fuel gas line (Fig. 44). The backfill operation continued into the summer 1976 along the blasted ditch where subsidence continued.

Subsidence may have been due to frozen or inadequately compacted backfill, thermokarst, or hydraulic erosion. One area where erosion was particularly severe was entirely covered with gravel during summer 1976 to form a turnout next to the Haul Road (Fig. 41 and App. B, site 133J1). Immediately north of the entrance to Galbraith Camp, jute netting, in addition to seeding, fertilizing, and cross drainage construction, were employed (Fig. 45).

During the winter of 1976-77 the fuel gas line was completed from just north of Happy Valley to Pump Station 1 at Prudhoe Bay. Construction



*Figure 39. Backhoe operating from highway scraping debris from snowpad, 26 May 1976.*



*Figure 40. Crane with bucket scraping debris from snowpad, 26 May 1976.*

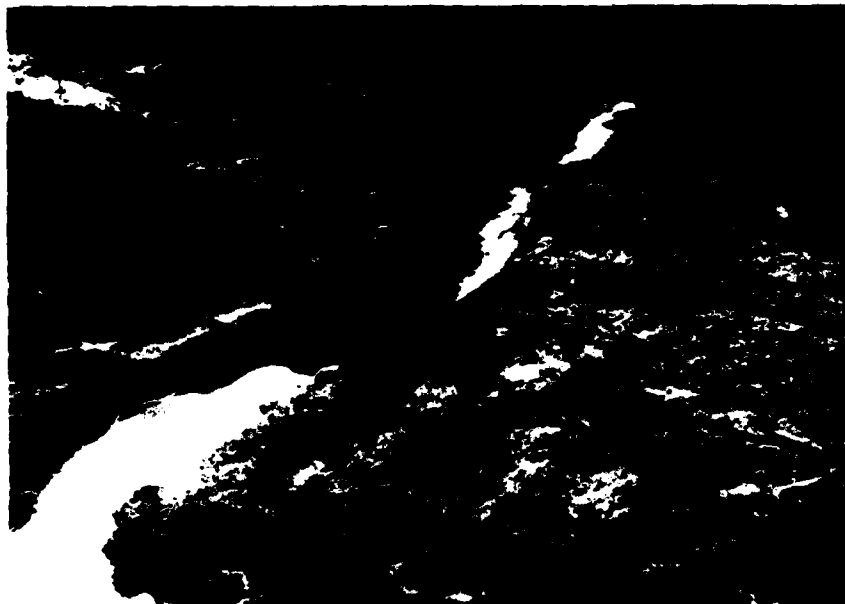


*Figure 41. Water eroding gravel in trench, 24 June 1976 (photograph by J. Brown). Note gully to right of middle of photograph and sand bags around right perimeter to divert water. This area was later covered with gravel to form a turnout. (See App. B, site 133J1)*



*Figure 42. Half culvert in background adjacent to road culvert and lined ditch channel downslope from the fuel gas line (photograph by J. Brown).*

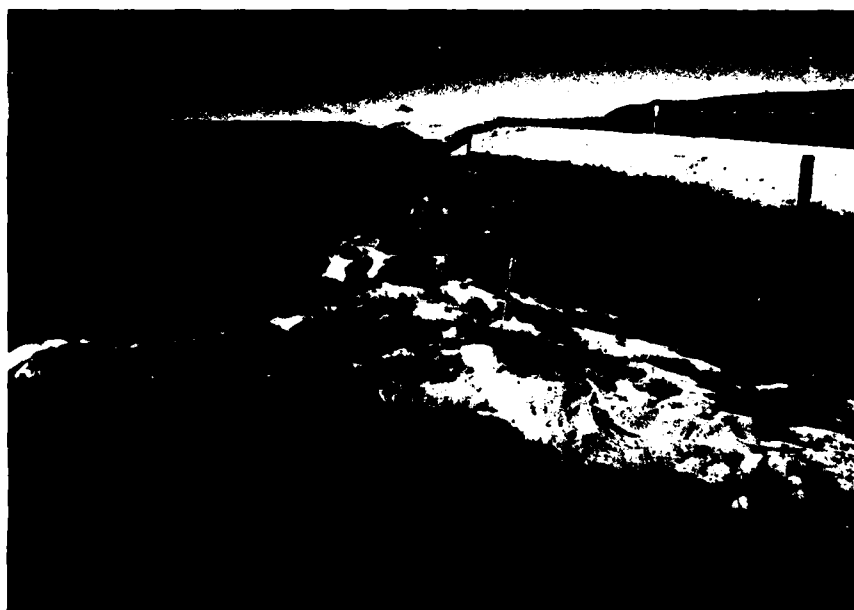




*Figure 43. Drainage channel adjacent to road culvert, 23 June 1976.*



*Figure 44. Sandbagged cross drainages over fuel gas line trench, 7 July 1977.*



*Figure 45. Severe erosion north of Galbraith Camp access road terminated by cross drainages over blasted trench. Seeding, fertilizing, and jute netting also used, 13 August 1978.*

activities during the period differed considerably from those of the previous year. The trench was dug by the Roc-Saw or Barber Greene trenchers. The bottom  $\frac{1}{2}$  m of trench in bedrock near Sagwon was completed by blasting. The top of the ditch in this area was 1 to 1.3 m across as opposed to 2 m across in some blasted sections of trench the previous year. In many instances the spoil from the ditching operations was deposited directly onto the road shoulder by the Roc-Saw or Barber Greene machines. This material was then graded across the road surface. However, thaw began and problems with slippery road surfaces and dust occurred. As a result of the dust, snow cover adjacent to the road melted very early in several northern areas.

Whereas long sections of trench remained open during the 1975-76 winter, the trench was allowed to rapidly backfill by blowing snow in 1976-77. Later the snow-filled trench was re-excavated, the pipe was placed into it, and the trench was immediately backfilled with gravel. Backfilling relied upon several different methods such as the wooly-worm or use of cranes with small buckets to place gravel directly into the trench. At no time was gravel observed to be dumped directly onto the snowpad as in the previous winter. As expected, this contributed to a

much cleaner snowpad and much less debris on the tundra after melt-off.

Erosion and more subsidence continued during summer 1977 along portions of the fuel gas line. Backfilling operations using a crane with a clam bucket operating from the road were observed in early August 1977 (Fig. 46). New half culverts and other cross drainages were also installed during 1977. However, the severity and frequency of problems were reduced in 1977 as compared to 1976. During early June 1978, large volumes of water were observed running along the fuel gas line on the Coastal Plain, but no new erosion problems were observed at that time. Some areas were again backfilled during 1978.

There were marked differences in the degree of tundra disturbance due to the various methods (blasting, Roc-Saw, Barber Green) of excavating the trench and backfilling along the fuel gas line. In order to assess these differences, permanent observation points were established in each of the two major physiographic regions (Arctic Foothills and Arctic Coastal Plain) for both the winters of 1975-76 and 1976-77. Sites were also selected along the blasted trench between Slope Mountain and Galbraith Lake (Fig. 47) to give a total of 16 observation points. Portions of this section were reseeded during early



*Figure 46. Clam bucket crane operating from the road used to backfill subsided section of fuel gas line trench, 3 August 1977.*



*Figure 47. Transition from backfilled blasted trench in foreground to backfilled Roc-Saw trench, 5 August 1977.*

summer 1976, but vegetative cover was generally less than 10% by late summer 1976 and remained low into 1978. Whenever possible, a transect to measure depth of thaw was established in 1976. Probing was performed between the road and the trench, between the trench and the outer edge of the snowpad, and at a number of points beyond the snowpad for control (Fig. 24). Measurement of thaw was repeated in 1978. Supplemental observations on percentage cover of debris (gravel and spoil), percentage cover of vascular plants, and species differences in vegetation damage were also recorded. Finally, a photograph was taken at each site for a permanent record (selected photographs are presented in App. C).

Data from the fuel gas line are summarized in Table 7 and general conclusions on the depth of thaw and vegetation damage and recovery are presented below.

1. Under the snowpad, microtopography was reduced due to such factors as debris filling the depressions and abraded tussock or hummock tops. Areas under thinner snowpad or with more pronounced microrelief were more severely affected.

2. Percentage cover by debris was much greater where gravel for the backfill was first placed on the snowpad. Consequently, the cover of vascular plants was reduced. (Fig. C10) between trench and road).

3. Depth of thaw was generally greater under the snowpad than in undisturbed tundra (Table 7). The increase in depth of thaw ranged up to 30 cm. In most cases the depth of thaw was greatest between the road and the fuel gas line trench. This is consistent with other thaw studies along the road (Brown and Berg 1978). The untrenched snowpad in 1976 caused less than 1 cm of average increase in the depth of thaw, whereas the same areas in 1978 (18 months after trenching) had an average depth of thaw increase of more than 10 cm. It is not known whether this difference is due to the debris deposited on the tundra following trenching, characteristics of the trench itself, or traffic associated with trenching and backfilling the fuel gas line. In most cases the amount of increased depth of thaw associated with the snowpad was greater in 1978 than in 1976. Since 1977 depths of thaw are not available, it is not known whether depths of thaw are still increasing or whether they have stabilized or have begun to decrease.

4. There were differences in species susceptibility to damage from snowpad construction and

debris. Upright shrubs such as *Salix* spp. and *Betula glandulosa* were frequently sheared off. Some impacted *Betula glandulosa* leaves died shortly after leafout in 1976; however, most of these plants recovered by 1978. Mosses, possibly due to their low stature, were more susceptible to damage from the debris. In at least several instances, *Arctagrostis latifolia* was flowering more profusely where the snowpad had been than outside it (Fig. 48). Percentage cover of vascular plants was very similar under the snowpad and on undisturbed tundra by 1978.

5. The backfilled trench formed a berm which appeared very narrow and well-defined where the Roc-Saw was used, especially where it was backfilled from the road.

6. Although snowpad construction, trenching, and backfilling operations did cause some environmental damage to the tundra, the degree of vegetation damage and permafrost degradation was relatively minor when the operation was carefully conducted and blasting was not used.

7. The use of sod chips cannot be evaluated because of the subsequent cleanup operations which dislodged most of them. However, in August 1977 some sod chips over the 1976 portion of the trench contained viable growth of cottongrass (*Eriophorum vaginatum*).

8. Success of revegetation over the trench was limited. Vegetative cover averaged less than 20% but was higher adjacent to the trench (Table 7). In wetter areas where the gravel fill in the trench was not raised above the surrounding ground level, the trench revegetated well (Fig. C22, 1978). Also in some areas of blasted trench revegetation significantly increased between 1976 and 1978 (Fig. C5, 1976 and C6, 1978).

9. A number of small diesel and crankcase oil spills resulted from machinery on the snowpad. The oil eventually reached the underlying vegetation, frequently killing it (Fig. 49).

#### **Island Lake and oil line snowpads**

Two other snowpads were used in the northern construction section: an experimental section of snowpad near Toolik used for construction of an elevated portion of the oil pipeline, and a short section of snowpad and insulated gravel used for access to Island Lake.

At Island Lake (site 114A, 5 km north of Galbraith Lake), a snow pad was constructed from the highway down to the lake so that water could be obtained for hydrotesting of the main line during late winter 1977. The snowpad was covered with extruded Styrofoam insulation and

**Table 7. Depth of thaw (cm), and vegetation cover observations along the fuel gas line pad (see Fig. 24 for position of sample points).**

Numbers in parentheses show standard errors of thaw measurements. Cover classes: 1 = 1-10%, 2 = 11-20%, ... 10 = 91-100%.

Depth of thaw				Vegetation cover												
Site	Toe-Trench (A)	Trench-snowpad edge (B)	(C) Undisturbed all snowpad	Toe-Trench (A)			Trench (B)			Trench-Snowpad edge (C)			Undisturbed			
				Debris	Live vasc.	Dead vasc.	Reveg.	ht. (cm)	Debris	Live vasc.	Dead vasc.	Debris	Live vasc.	Dead vasc.		
Foothills sites																
<i>Blasted and backhoe</i>																
116-1 1976	87	65 (13.0)	56.7 (4.3)	70.5 (10.7)	10	0	—	—	1	20	7	3	—	—	—	—
117-1 1976		Too rocky to probe			10	9	0	0	1	60	4	5	1	1	6	1
1978					9	1	—	—	1	5	9	1	—	—	—	5
					9	8	0	0	3	70	5	3	1	2	1	6
118-1 1976		Too rocky to probe			0	0	—	—	1	15	6	3	—	—	—	—
1978					2	8	1	0	6	50	3	4	2	1	4	3
Roc-Saw																
124-1 1976	51.7 (5.0)	57.0 (9.5)	42.8 (3.3)	54.3 (5.2)	8	1	—	—	—	—	6	4	—	—	—	—
1978	62.3 (1.7)	54.7 (1.5)	30.3 (1.8)	58.5 (1.9)	3	7	1	3	1	10	1	4	1	8	1	5
124-2 1976	45.0 (6.7)	45.3 (2.6)	39.8 (5.4)	45.2 (3.2)	6	3	—	—	—	—	1	0	—	—	—	—
1978	58.0 (3.5)	34.3 (0.9)	31.7 (2.0)	36.2 (5.5)	6	2	1	1	1	5	1	6	2	4	1	7
124-3 1976	41.3 (2.3)	42.0 (2.5)	33.5 (6.9)	41.7 (1.5)	4	4	—	—	—	—	1	6	—	—	—	—
1978	69.3 (4.1)	38.7 (4.7)	38.7 (2.4)	54.0 (7.4)	6	3	1	1	1	5	1	6	2	1	2	2
124-4 1976	Unditched		37.5 (9.6)	30.8 (1.6)	7	3	1	1	2	5	6	2	3	1	1	8
1978	50.7 (4.8)	45.3 (4.8)	35.7 (2.8)	48.0 (3.3)	7	3	1	1	2	5	6	2	3	1	1	8
125-1 1976	Unditched		29.5 (1.0)	35.2 (2.3)	2	5	1	6	2	20	1	5	1	8	1	3
1978	37.7 (0.3)	38.3 (1.9)	31.7 (1.2)	38.0 (0.9)	2	5	1	6	2	20	1	5	1	8	1	3
125-2 1976	Unditched, gravel thawed more than 100 cm		56.0 (1.2)	81.7 (1.4)	8	2	1	1	1	5	2	3	3	1	1	4
1978	80.7 (2.4)	82.7 (1.8)	38.7 (5.2)	37.4 (5.9)	2	3	—	—	—	—	—	—	—	—	4	1
127-1 1976	Unditched		29.3 (1.8)	60.3 (3.5)	8	2	1	1	1	15	2	4	3	2	1	7
1978	65.0 (1.2)	55.7 (6.1)													2	5
Coastal Plain sites																
Roc-Saw																
128-1 1976	70.3 (5.9)	65.7 (2.3)	51.3 (0.9)	68.0 (3.0)	4	6	—	—	—	—	1	10	—	—	—	—
129-1 1976	76.5 (0.5)	57.0 (3.5)	40.3 (2.3)	64.8 (5.2)	2	—	—	—	—	—	8	—	—	—	—	—
129-2 1976	63.7 (0.3)	62.3 (3.7)	63.9 (1.7)	45.3 (2.7)	—	—	—	—	—	—	—	—	—	—	—	—
1978	71.7 (6.3)	69.0 (3.5)	40.7 (0.3)	70.3 (1.7)	9	6	2	0	1	15	8	4	5	10	2	4
130-1 1976	Unditched		48.3 (1.5)	49.0 (1.4)	3	5	—	—	2	—	—	—	—	—	—	6
1978	63.0 (3.0)	56.0 (2.3)	51.7 (2.3)	59.5 (2.3)	10	5	2	0	1	2	9	5	5	1	5	3
130-2 1976	Unditched		58.7 (2.4)	56.4 (1.3)	2	6	—	—	2	—	—	—	—	—	—	3
1978	62.7 (2.4)	71.0 (2.1)	58.3 (1.2)	66.8 (2.3)	10	5	2	1	1	7	8	3	5	1	7	1
130-3 1976	Unditched		64.4 (0.6)	58.6 (4.7)	3	4	—	—	3	—	—	—	—	—	4	7
1978	68.0 (0.6)	66.7 (1.8)	72.0 (2.3)	67.3 (0.9)	9	6	4	1	1	10	9	6	6	1	8	1



*Figure 48. Increased flowering of Arctagrostis latifolia under area of snowpad, 13 August 1978.*



*Figure 49. Oil spill through snowpad which killed the underlying vegetation, 13 August 1978.*



Figure 50. Area of snowpad to Island Lake on 6 August 1977. Note debris and subtle vegetation changes along edge of snowpad position.

a topping of gravel. This type of construction permitted the road to be used later in the spring than would be possible with an uninsulated snowpad. After hydrotesting was completed, the gravel and insulation were removed. The impact of the road was visible in August 1977 (Fig. 50) but was very difficult to find by August 1978 (Fig. 51). In fact, the main impact noticeable in 1978 was debris, ranging from gravel to insulation, which had not been completely removed (Fig. 52).

The oil pipeline snowpad was constructed from snow collected by a snow fence (Fig. 53). The snow was compacted in a manner similar to that used along the fuel gas pipeline and holes for the vertical support members (VSM's) of the oil pipeline were drilled through the snowpad. The snowpad was maintained and excess snow was removed by grading operations (Johnson and Collins 1980).

In a manner analogous to the fuel gas line study, permanent photographic points and depth of thaw transects were set out along the oil pipeline snowpad. Although data from these transects are very limited (Table 8), some tentative conclusions can be made. Depth of thaw in 1978 was increased only slightly under the snow-

pad near the VSM's (6.4 cm) but was increased significantly (18.7 cm) under the traffic lanes used on the snowpad.

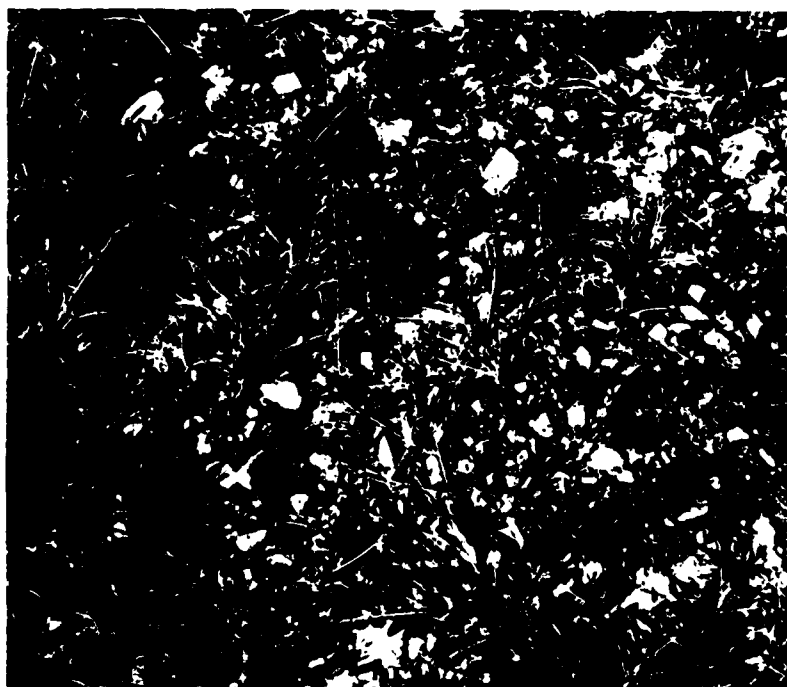
Generally, there was much less debris than along the fuel gas line (Fig. 54). However, there did seem to be much greater damage to tussocks with some exposure of organic and mineral soil along the oil pipeline snowpad (Fig. 55). Once again, moss and upright shrubs sustained a disproportionate amount of damage, although shrubs had largely recovered by 1978. The percentage cover of mosses was reduced in both 1976 and 1978, whereas vascular plant cover was not affected (Table 8). Much of the herbaceous regrowth was from grasses, primarily *Arctagrostis latifolia* (Fig. 56). *A. latifolia* also produced numerous seed heads during 1978 in the area of the traffic lane of the snowpad (Fig. 57). This increased seed production may have been caused by the greater depth of thaw associated with the traffic lane rather than the snowpad itself. Little increase in flowering was observed near the VSM's.

#### Oil spills and revegetation

During construction and the initial operation of the trans-Alaska pipeline system through the



*Figure 51. Area of Island Lake snowpad on 14 August 1978. Little visible effect is obvious except gravel for debris.*



*Figure 52. Close-up of debris left from Island Lake snowpad (14 August 1978). Light-colored material is insulation.*



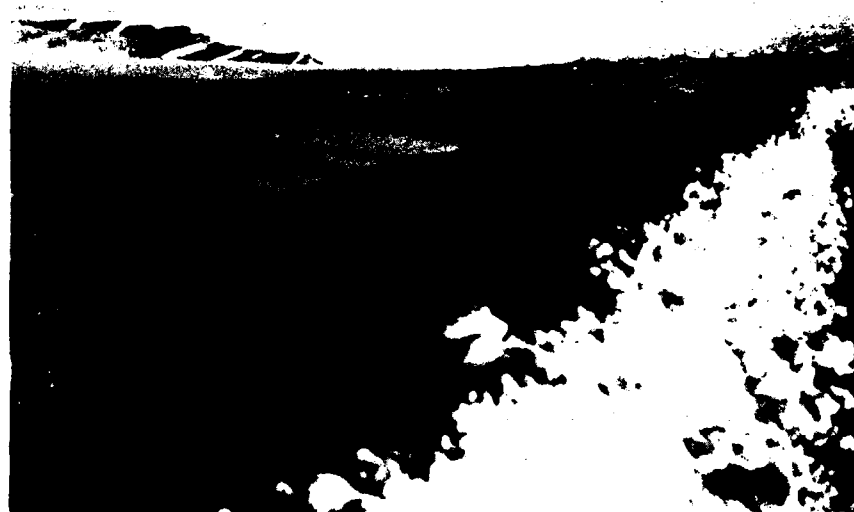


Figure 53. Snow fence used to collect snow for construction of the oil pipeline snowpad between Kuparuk River and Slope Mountain, 3 February 1976.

Table 8. Snowpad observations along the oil pipeline (1976 and 1978).

Average depth of thaw*				
	Travel Lane	VSM Portion	Undisturbed	
1976	39.3 (3.4)	40.8 (2.6)	37.8 (1.1)	
1978	73.0 (1.5)	50.7 (8.7)	44.3 (2.3)	

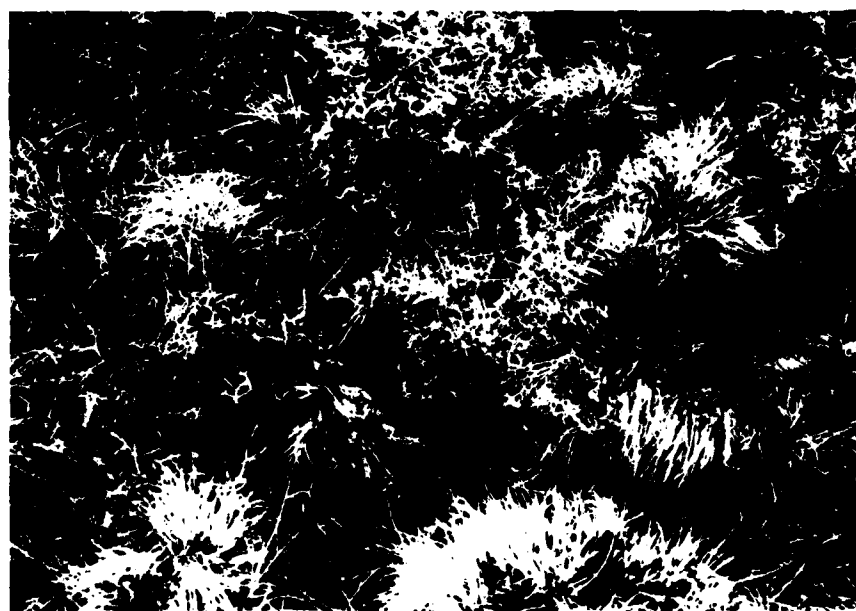
Ground Cover Class†				
	Debris (dust, gravel, stones)	Dead (including organic)	Live vascular	Live non-vascular (lichens, mosses)
1976				
Snowpad	2.5	4	2.5	2.5
Control	-	1.5	3	5.5
1978				
Snowpad	1	3	5.5	5
Control	-	1	5.5	7

\*[cm (std. error)]

†1-10, where 1 = 10% ground cover, 2 = 11-20%, etc.



*Figure 54. Area that lay beneath oil pipeline snowpad, 19 August 1976.*



*Figure 55. Abraded tussocks resulting from oil pipeline snowpad, 19 August 1976 (see Fig. 54).*

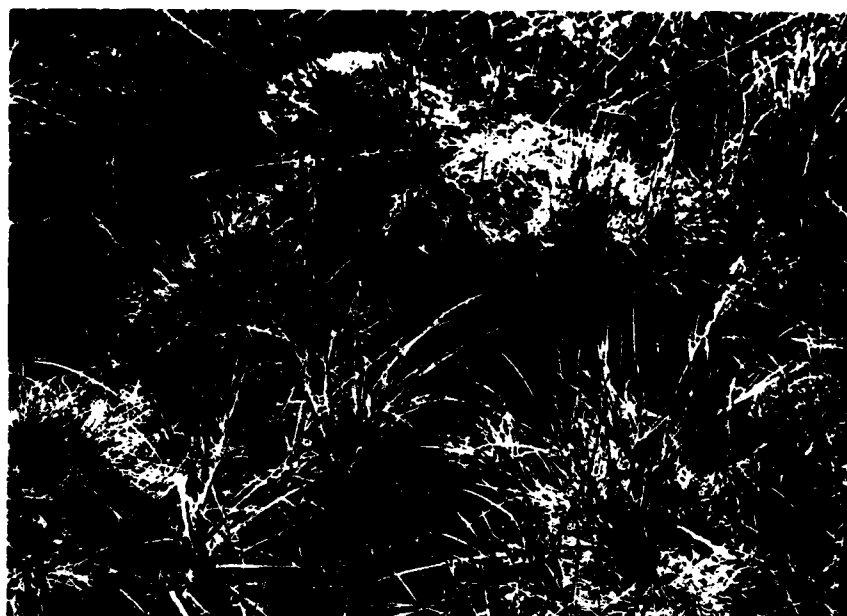


Figure 56. Regrowth from damaged tussocks, much of the taller grass is *Arctagrostis latifolia*, 14 August 1978.



Figure 57. View across oil pipeline snowpad towards gas feeder line and road, 14 August 1978. Abundant seed heads of *Arctagrostis latifolia* can be seen where the traffic lane was on the snowpad (middle of photo).



Figure 58. View of burned diesel fuel spill (resulting from overturned tanker) in vicinity of Happy Valley, 23 June 1976.

end of 1977, more than 16,000 oil spills occurred along the pipeline route. These spills totaled more than 700,000 gal.\* Most involved refined petroleum products. Although many of the spills were confined to gravel pads or to waterways, some occurred on terrestrial vegetation. Diesel spills have been particularly severe in their damage upon vegetation. A 26 May 1976 tanker spill on the tundra near Happy Valley caused extensive kill of the vegetation despite the use of absorbents and burning to remove most of the diesel fuel (Figs. 58 and 59). Vegetative regrowth resulted in less than 5% cover on 29 August 1976. Similar results were reported by Walker et al. (1978) with experimental diesel oil spills and by Lawson et al. (1978) for 28-year-old diesel spills in the Arctic.

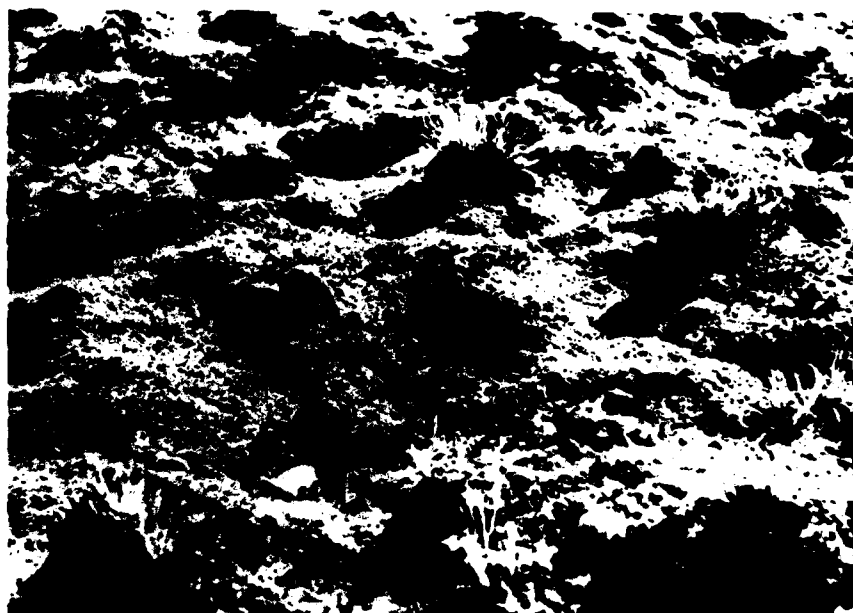
More dramatic, but less frequent, spills of crude oil have also occurred along the pipeline. The two largest spills occurred at valve 7 (AS 133,) on the Coastal Plain north of Franklin Bluffs and at Steele Creek (AS 59) in the boreal forest just south of Fairbanks. At valve 7 on 19 July 1977 over 300,000 liters (80,000 gal.) of

crude oil was spilled (Walker et al. 1978). The oil, under high pressure, shot a considerable distance into the air and the spray was carried more than 1200 m downwind. An area up to 250 m away from the valve was heavily coated with oil (Fig. 60). Cleanup efforts on the affected tundra relied almost exclusively upon hand labor. Ditches were dug around and through the most heavily saturated area in order to collect oil so that it could be removed by suction pumps. Sandbags were later placed around this area and water from a nearby lake was used to flood it and float the oil to the surface. Oil was then skimmed off the water surface by suction pumps. Walker et al. (1978) present a vegetation map of this area.

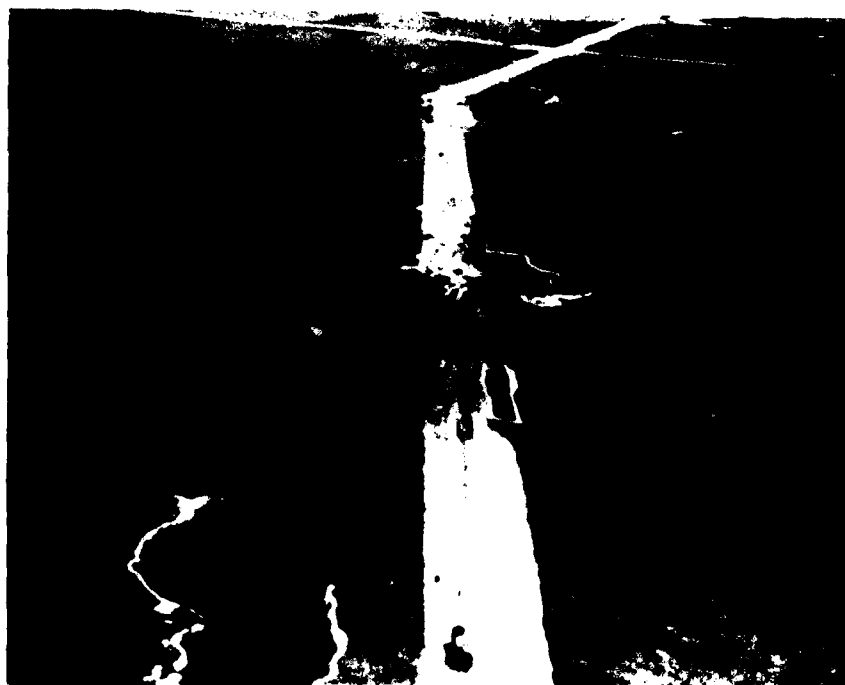
A major impact of the valve 7 spill was the effect of repeated trampling by cleanup workers within the most heavily contaminated area. The thawed soil, heavily oil saturated, was churned so that it was impossible to differentiate between oil-induced and trampling-induced damage to the vegetation (Fig. 61).

When the site was first visited in early August 1977, cleanup was still in progress and the oil-saturated area was flooded. However, the

\*L. Dietrick, Alaska Department of Environmental Conservation, personal communication, 1978.



*Figure 59. Closeup view of diesel spill showing only sparse regrowth from cottongrass tussocks, 23 June 1976.*



*Figure 60. Aerial view of valve 7 crude oil spill. Note fanning out of spray downwind. (Photograph courtesy of Joint Fish and Wildlife Advisory Team, July 1977).*



*Figure 61. Heavily impacted area of valve 7 oil spill. Note experimental plots in center (stakes) and sandbags in background used to contain oil during cleanup, 12 August 1978.*

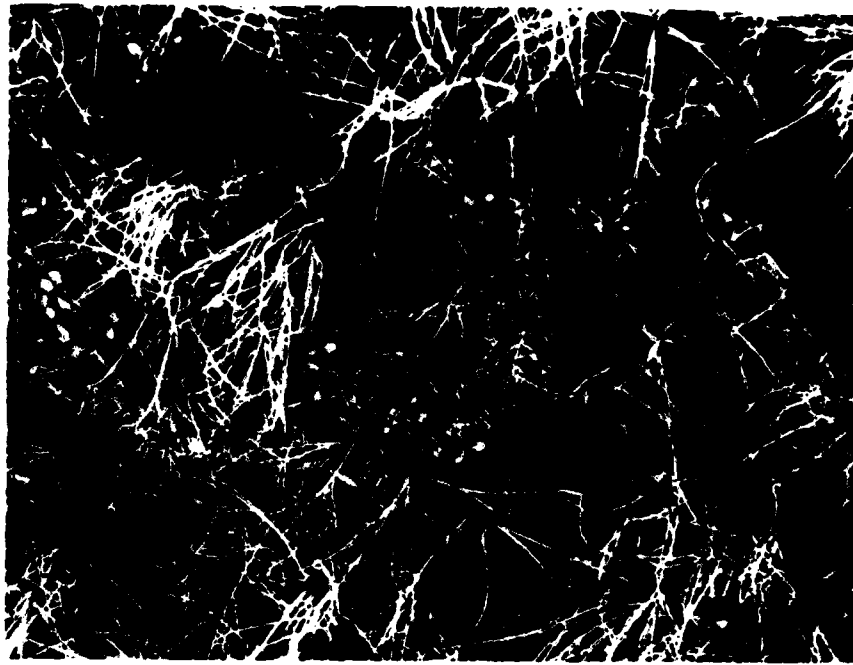
amount of live vegetative cover increased with distance from the valve. At a distance of 150 m, only the sides of the monocot stems facing the spray were oil-coated and the moss layer was not saturated with oil. An interesting aspect of the spill at this time was a rapid regrowth of monocot species (mainly *Carex*, Walker et al. 1978) in the areas sprayed by oil.

When the site was revisited in August 1978, Alyeska had established fertilizer, seed, and transplant experiments within the heavily impacted area (Fig. 61). Very little regrowth was observed within the oil impacted area immediately adjacent to the workpad; however, some 20 to 30 m farther away near the sandbag dike, up to 10% live vegetative cover was noted. This result indicates that the oil did not completely kill the vegetation and that some regrowth might have occurred if trampling had not been so intense. Although oil could be detected by smell in this area, there was no visible indication of any oily layers at the surface.

At 20 m from the valve, the oil saturated the litter layer but had only penetrated the organic layer 1 to 2 cm. At 60 m, there was 50% live cover despite a 90% cover of oil on the ground-surface (Fig. 62). Finally at 160-m distance, there

was little visible effect on the upright vegetation and oil coated less than 20% of the ground surface.

At Steele Creek more than 1,900,000 liters (500,000 gal.) of crude oil spilled on 2 February 1978 following a sabotage explosion. The oil shot down into the workpad and then sprayed or flowed out onto the adjacent vegetation. The spill occurred while the ground was snow covered, but the oil flowed both over and under the snow. Cleanup relied upon suction pumps to remove most of the oil although absorbent material was also used. The severely impacted area was subsequently isolated from Steele Creek by a gravel dike and then the oily saturated area was bladed and removed (while still frozen) by a bulldozer. The oiled area, which was subsequently burned twice after spring thaw, was ignited without difficulty in contrast to experimental results (McKendrick and Mitchell 1978a). Despite these efforts, oil continued to be removed by suction pumping and by absorbents at least through August 1978. When the site was visited in early September 1978, the gravel dike had been seeded and fertilized. Parts of the oil contaminated area had been tilled and fertilized, but not seeded. However, there was some



*Figure 62. Regrowth of shrubs and monocots, 60 m downwind from valve 7, 12 August 1978.*



*Figure 63. View of Steele Creek spill after cleanup and burning. Some oil impacted areas have regrowth of native grasses.*



Figure 64. Experimental restoration site (MS 117-1, 2), 13 August 1978. Note growth of cottongrass tussocks (sod) and reseeded plots in foreground.

regrowth of native grasses within the burned zone (Fig. 63). Survival was probably due to the high moisture and frozen conditions of the site during burning. McKendrick and Mitchell (1978a) report similar results. The area was subsequently refertilized and seeded during 1979 (Hubbard 1980).

Evidence so far indicates that large crude oil spills may not kill all vegetation even in heavily saturated areas (Jenkins et al. 1978, Johnson et al. 1980, McKendrick and Mitchell 1978b). Although Alyeska is conducting limited research on revegetating one of the larger oil spills (at valve 7), artificial revegetation has not been used as a standard procedure on oiled areas. It may be that the native vegetation can adequately recover on wetter sites if proper cleanup procedures are employed.

#### CRREL RESTORATION SITES

Two CRREL experimental restoration sites were established in northern Alaska along the Haul Road (MS 117-1,2 and MS 127-2.18, Fig. 64 and 65). There were two main objectives of this research. The first objective was to compare existing revegetation methods (such as Alyeska's) with experimental techniques for promoting long-term tundra recovery or restoration. Subjects to be examined included the rate of revegetation associated with each technique and the effect upon the re-establishment of native species of vegetation. A second objective was to

provide sites for related research, such as methods for increasing seed set from undisturbed tundra. This project has been conducted in cooperation with Dr. F.S. Chapin, University of Alaska, and is reported upon separately (Brown and Berg 1980).

Although the experimental design varied somewhat according to the site, variables tested at each site included fertilizers, shrub cuttings (*Salix pulchra* and *Betula nana*), Alyeska North Slope grass seed mix, seed from a native grass-bluejoint reedgrass (*Calamagrostis canadensis*) tundra sod (mainly *Eriophorum vaginatum*) placed by hand and packed to ensure good soil contact, and combinations of treatments such as fertilizer and seed, sod-seed-fertilizer, and seed-fertilizer-cuttings.

The Sagwon site (MS 127-2.1B) was cleared by bulldozer in late August 1976. Shrub cuttings and sodding were transplanted at that time. The Toolik site (MS 117-1,2) was cleared in early June 1977 in order to determine the significance of a shallow disturbance which removed less of the pre-existing active layer. The remaining test plots at both sites were established in early July 1977 except for additional shrub cuttings at the Toolik site which were planted in early August 1977.

The sites were observed in August 1977 and August 1978. Depth of thaw measurements, percentage survival, percentage cover, and maximum height data are given in Table 9 for August 1978.





Figure 65. Willow (*Salix pulchra*) cuttings at Sagwon (MS 127-2.1B) restoration site (17 August 1976).

Although these data are still preliminary since only one and a half growing seasons have been evaluated for most treatments, the following tentative results can be made:

1. Willow cuttings (*Salix pulchra*) and tundra sodding (*Eriophorum vaginatum*) offer feasible means of re-establishing upland native vegetation in the Arctic. Survival is highest when planting is accomplished late in August as compared to early July.

2. Birch (*Betula nana*) cuttings have low survival rates.

3. As of August 1978, there was little vegetative cover provided by the native species which are re-establishing on the sites.

4. Bluejoint seed alone provided a greater cover than the Alyeska grass seed mix after one and a half growing seasons.

## CONCLUSIONS

1. Revegetation along the trans-Alaska pipeline system is based primarily upon currently accepted practices of mulching, fertilizing, and seeding with adapted agronomic grass species. Over 90% of disturbed areas (excluding camps)

had been initially seeded by August 1978.

2. Attempts to use native grass species in the seed mix were limited. Seed increase programs for native seed did not produce enough seed in the short time allowed to constitute a major portion of the seed mix. However, research by Alyeska and others has increased the likelihood of native seed production in the future.

3. Alyeska's revegetation program generally improved from 1975-1978 in terms of seedbed preparation, scheduling, and availability of supplies and equipment. In large part this was due to a lessening of construction activity so that environmental matters were given higher priority. But experience gained by Alyeska personnel also contributed to improvements in the program.

4. Some problems were irremediable such as the loss of topsoil and organics which were buried or otherwise lost during initial clearing operations.

5. Temporary erosion control was a recurring problem along the trans-Alaska pipeline. This problem could have been reduced, along with other environmental problems, by an improved quality assurance program.

6. Native species are only slowly reinvading

Table 9. CRREL restoration results.

	<i>Sagwon</i>		<i>Toolik</i>	
<i>Depth of thaw (cm)</i>	<i>Control</i>	<i>Bladed</i>	<i>Control</i>	<i>Bladed</i>
1977	38.4	43.5	42	36.4
1978	38.9	61.0	42.4	56.8
<i>Percent survival to August 1978 of shrub cuttings:</i>	<i>Willow</i>	<i>Birch</i>	<i>Willow</i>	<i>Birch</i>
Late August 1976	100%	37%		
Late August 1977			95%	45%
Early June 1977	75%	15%	88%	20%
Early July 1977 plus				
Alyeska fertilizer	88%	0%	72%	20%
Early July 1977 plus				
Alyeska seed and fertilizer	77%	0%	65%	20%
<i>Growth of Sod to 1978*</i>	<i>Good</i>	<i>Fair</i>	<i>Good</i>	<i>Fair</i> <i>Poor</i>
Late August 1976	91%	9%		
Early July 1977				
sod alone	60%	40%	80%	20%
Sod & Alyeska fertilizer			80%	15%
Sod & Alyeska seed & fertilizer 75%	25%		70%	25% 5%
<i>Percent vascular plant cover to August 1978</i>				
Control	<5%		<5%	
Alyeska fertilizer	<5%		<5%	
Alyeska seed & fertilizer	40%		35%	
Bluejoint & complete (N,P,K) fertilizer	40%		55%	

\*Good = >30% live vegetation cover, Fair = 10-29% live vegetation cover  
Poor = 1-9% live vegetation cover

NOTE: Many undisturbed cottongrass tussocks in these areas had 50-70% cover of standing dead.

revegetated areas except primarily at more southerly locations between Glenallen to Valdez. Exotic weed species have been observed at a number of revegetated sites, although it is not known how long they will persist.

7. Native animals (moose, caribou, dall sheep, etc.) have heavily grazed some revegetated areas.

8. Criteria for successful restoration are being used by the Alaska Pipeline Office to determine if Alyeska has met minimum standards for revegetated areas.

9. Some revegetated areas have 80-90% grass cover from the seed mix. The long-term persistence of these exotic species and their effect upon reestablishment of native vegetation cannot be evaluated at this time.

10. The visual impact engineering (VIE) program using transplants of native trees and shrubs

has initially been very successful.

11. The willow cutting (*Salix alaxensis*) program to replace lost wildlife browse was almost a total failure during 1977. However, the 1978 program using unrooted cuttings looks very promising.

12. Snowpad construction and trenching for the fuel gas line varied in the extent and severity of terrain disturbance. The type of trenching (blasting vs use of Roc-Saw or Barber Greene trenchers) and the method of backfill were important variables. Vegetation damage was minimized by careful construction of the snowpad to minimize shearing of underlying vegetation, placement of the trenching machine spoil directly on the road side, and backfilling from the adjacent road directly into the trench.

13. Depth of thaw generally increased under snowpads used by heavy traffic. However, in-

creases were not detrimental. Some grasses responded by greatly increased seed production in the area formerly covered by the snow pads. Low growing vegetation such as mosses and lichens were most heavily impacted by snowpads, primarily because of debris which was left after the snowpad melted.

14. Oil spills have been numerous (more than 16,000 through 1977) during the construction and initial operation of TAPS. Most of these were refined petroleum spills which are highly toxic to vegetation. Two large crude oil spills along TAPS covered large areas but were not as toxic to vegetation as diesel fuel spills. Vegetation at valve 7 is rapidly recovering in all but the heavily trampled cleanup area. At Steele Creek some vegetation is regrowing after being burned twice following initial cleanup.

15. Restoration studies by CRREL show that willow cuttings (*Salix pulchra*) and tundra sodding (*Eriophorum vaginatum*) are feasible means of reestablishing upland arctic vegetation. Studies will continue to determine long term effects of experimental restoration methods in comparison to existing revegetation techniques.

## RECOMMENDATIONS

The large scale and wide geographical extent (800 miles) of the trans-Alaska pipeline route has provided a huge experimental laboratory for evaluating revegetation techniques and environmental safeguards. The following recommendations are based upon observations made by the author during 1975-1978.

1. Proper planning and selection of material sites minimizes aesthetic impact as well as preventing costly restoration measures (e.g. Sukakpak Mountain).

2. Saving of organics and topsoil should be emphasized at the start of the project.

3. In particularly poor growing sites (e.g. coarse material sites in the Arctic) reuse of fine-grained disposal material for a seed bed to enhance nutrient and moisture conditions should be considered.

4. Adequate lead time for production of native seeds is mandatory. Native species (seeds or transplants) offer advantages and are preferable whenever possible.

5. Environmental quality assurance programs must have adequate authority. Proper programs will reduce impact as well as facilitating restoration of disturbed sites.

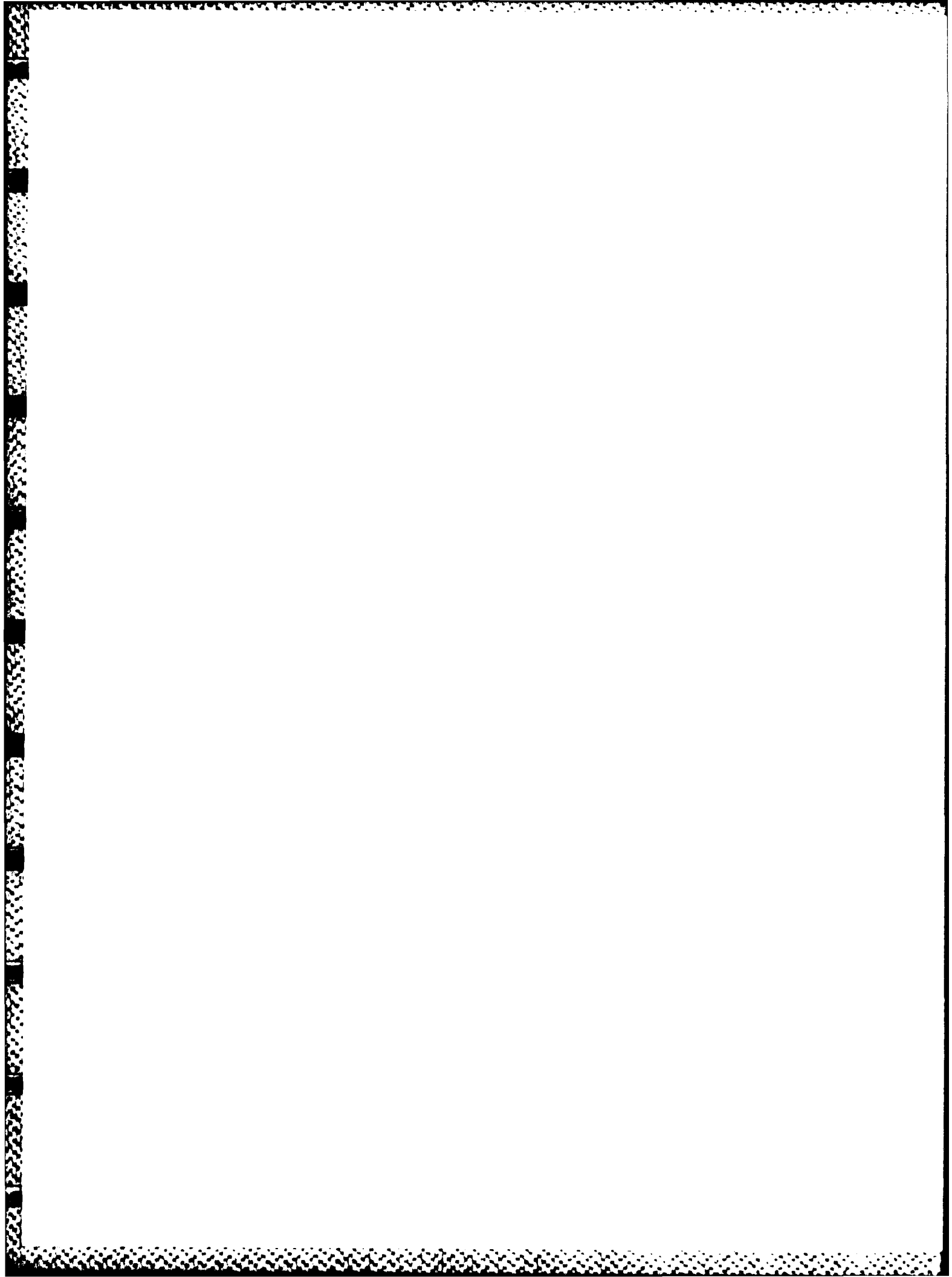
6. Since alternative methods for using native species are still being developed, and there is no single method which is best for all sites and situations, research in these areas should continue.

7. Environmental surveillance agencies should have adequate authority to enforce regulations at the outset of construction projects. Otherwise equipment and personnel will be unavailable for revegetation and other environmental measures until construction activity slows.

## LITERATURE CITED

- Arctic Environmental Council (1977) Report on the 4th on-site visit to the trans-Alaska pipeline system, September 18-24, 1977. Arctic Institute of North America.
- Berg, R.L., J. Brown, and R.K. Haugen (1978) Thaw penetration and permafrost conditions associated with the Liven-good to Prudhoe Bay Road, Alaska. In *Proceedings of the Third International Conference on Permafrost*, National Research Council of Canada, vol. 1, p. 616-621.
- Bliss, L.C. (1979) Vegetation and revegetation within permafrost terrain. In *Proceedings of the Third International Conference on Permafrost*, National Research Council of Canada, vol. 2, p. 31-50.
- Bock, G.R. (1979) Arctic winter construction and cost estimating of the North Slope fuel gas line. In *Pipelines in Adverse Environments—A State of the Art*. New York: American Society of Civil Engineers, vol. 2 p. 511-520.
- Brown, J. (Ed.) (1978) Ecological baseline investigations along the Yukon River-Prudhoe Bay Haul road, Alaska. CRREL Special Report 78-13. ADA 060255.
- Brown, J. and N.A. Grave (1979) Physical and thermal disturbance and protection of permafrost. In *Proceedings of the Third International Conference on Permafrost*. National Research Council of Canada, vol. 2, p. 51-92.
- Brown, J. and R.L. Berg (Eds.) (1980) Environmental engineering and ecological baseline investigations along the Yukon River-Prudhoe Bay haul road, Alaska, CRREL Report 80-19. ADA 094497.
- Brown, R.W., R.S. Johnson and Keith Van Cleve (1978) Rehabilitation problems in arctic and subarctic regions, p. 23-44. In *Reclamation of Drastically Disturbed Lands* (Schaller and Sutton, Eds.).
- Carson, A. and G. Milke (1976) Environmental problems caused by construction of a fuel gas line from Prudhoe Bay to Pump Station No. 4. In *Proceedings 27th Alaska Science Conference*, (D. Norton, Ed.), Alaska Division of AAAS, vol. II, p. 58-65.
- Hartman C. and P. Johnson (1978) Environmental atlas of Alaska. Institute of Water Resources, University of Alaska, Fairbanks.
- Hemming, J.E. and K.A. Morehouse (1976) Wildlife atlas: Trans-Alaska oil pipeline, Valdez to Prudhoe Bay. Joint State/Federal Fish and Wildlife Advisory Team Special Report Number 3.
- Hubbard, J. (1980) Revegetation restoration for the trans-Alaska pipeline system, p. 113-125. In *Proceedings, High Altitude Revegetation Workshop No. 4* (C. Jackson and M. Schuster, Eds.). Colorado School of Mines. Golden, Colorado.
- Jenkins, T., L. Johnson, C. Collins and T. McFadden (1978) The physical, chemical, and biological effects of crude oil spills

- on black spruce forest, Interior Alaska, *Arctic*, vol. 3, no. 3, p. 305-323.
- Johnson, A. and S. Kubanis** (1980) The revegetation of disturbed sites along the Yukon River to Prudhoe Bay Haul Road, p. 16-29. In *Proceedings: High Altitude Revegetation Workshop No. 4* (C. Jackson and M. Schuster, Eds.). Colorado School of Mines, Golden Colorado.
- Johnson, L.** (1978) Biological restoration strategies in relation to nutrients at a subarctic site in Fairbanks, Alaska. In *Proceedings of the Third International Conference on Permafrost*, National Research Council of Canada, vol. 1, p. 460-466.
- Johnson, L., W. Quinn and J. Brown** (1977) Revegetation and erosion control observations along the trans-Alaska pipeline, 1975 summer construction season, CRREL Special Report 77-8, ADA 038416.
- Johnson, L. and K. Van Cleve** (1976) Revegetation in arctic and subarctic North America: A literature review. CRREL Report 76-15, ADA 027406.
- Johnson, L., E. Sparrow, C. Collins, T. Jenkins, C. Davenport, and T. McFadden** (1980) The fate and effects of crude oil spilled on subarctic permafrost terrain in Interior Alaska. CRREL Report (in press), EPA 600/3-80-040.
- Johnson, P. and C. Collins** (1980) Snowpads used for pipeline construction in 1976, CRREL Report 80-17.
- Kavanagh, N.L.** (1977) Interagency approach to environmental surveillance. A history and evaluation of the Joint State/Federal Fish and Wildlife Advisory Team. JSFFWAT Special Report 12.
- Keyes P.** (1976) Ice and snow construction: Workpads, roads, airfields, and bridges. *Proceedings of the Second International Symposium on Cold Regions Engineering*, p. 369-382.
- Kubanis, S.A.** (1980) Recolonization by native and introduced plant species along the Yukon River-Prudhoe Bay Haul Road, Alaska. M.S. Thesis, San Diego State University (unpublished).
- Lawson, D., J. Brown, K. Everett, A. Johnson, V. Komárková, B. Murray, D. Murray and P. Webber** (1978) Tundra disturbances and recovery following the 1949 exploratory drilling, Fish Creek, Northern Alaska. CRREL Report 78-28. ADA065192.
- Lucas, E.R.** (1975) Revegetation of pipeline route to follow careful plan. *Alyeska Reports*, July, p. 10-11.
- McKendrick, J.D. and W. Mitchell** (1978a) Effects of burning crude oil spilled onto six habitat types in Alaska. *Arctic*, vol. 31, no. 3, p. 277-295.
- McKendrick, J.D. and W. Mitchell** (1978b) Fertilizing and seeding oil-damaged tundra to effect vegetation recovery: Prudhoe Bay Alaska. *Arctic*, vol. 31, no. 3, p. 296-304.
- Mechanics Research Inc. (MRI)** (1977) Environmental surveillance during construction of the Trans-Alaska Pipeline System. Prepared for Alaska Pipeline Office.
- Mitchell, W.** (1979) Three varieties of native Alaskan grasses for revegetation purposes. Agricultural Experiment Station, University of Alaska, Circular 32.
- Mitchell, W. and J.D. McKendrick** (1974a) Tundra rehabilitation research: Prudhoe Bay and Palmer Research Center. 1973 Progress report to Alyeska Pipeline Service Company, ARCO, Canadian Arctic Gas Ltd., Exxon, Shell Oil and Union Oil. Institute of Agricultural Science, University of Alaska, Fairbanks.
- Mitchell, W. and J. McKendrick** (1974b) Tundra rehabilitation research: Prudhoe Bay and Palmer Research Center. 1973-74 Summary report to Alyeska Pipeline Service Company, ARCO, Canadian Arctic Gas Ltd., Exxon, Shell Oil, and Union Oil, Institute of Agricultural Science, University of Alaska, Fairbanks.
- Morehouse, T.A., R.A. Chidders, L.E. Leash** (1978) Fish and wildlife protection in the planning and construction of the trans-Alaska oil pipeline. Fish and Wildlife Service, 78-70, Washington, D.C.
- Pamplin, W.L.** (1979) Construction-related impacts of the Trans-Alaska pipeline system on terrestrial wildlife habitats, Special Report No. 24. Joint State/Federal Fish and Wildlife Advisory Team, U.S. Department of Interior.
- Sutton, R.K.** (1975) Why native plants are used more. *Soil Water Conservation*, vol. 30, no. 5, p. 240-242.
- Van Cleve, K. and J. Manthei** (1972) Summary report of the tundra-taiga surface stabilization study. Submitted to Alyeska Pipeline Service Co., Inc. Institute of Arctic Biology, University of Alaska, Fairbanks.
- Van Cleve, K. and J. Manthei** (1973) 1973 Report on tundra-taiga surface stabilization study. Submitted to Alyeska Pipeline Service Co., Inc. Institute of Arctic Biology, University of Alaska, Fairbanks.
- Walker, D., P. Webber, K. Everett, and J. Brown** (1978) Effects of crude and diesel oil spills on plant communities at Prudhoe Bay, Alaska, and the derivation of oil spill sensitivity maps. *Arctic*, vol. 31, no. 3, p. 242-259.
- Webber, P. and J. Ives** (1978) Damage and recovery of tundra vegetation. *Environmental Conservation*, vol. 5, no. 3, p. 171-182.
- Williams, G.** (1976) Drainage and erosion at construction sites. In *Canadian Building Digest*. Division of Building Research, National Research Council of Canada, vol. 1831-4, no. 183, p. 1-4.
- Younkin, W. (Ed.)** (1976) Revegetation studies in the northern Mackenzie Valley region. Arctic Gas Biological Report Series, vol. 38.
- Zasada, J., P. Holloway and R. Densmore** (1977) Considerations for the use of hardwood stem cuttings. In *Proceedings of the Surface Protection Seminar* (M. Evans, Ed.), Bureau of Land Management, p. 148-157.
- Zemansky, G.** (1976) Symbolic environmental monitoring on the trans-Alaska oil pipeline. *Proceedings, 27th Alaska Science Conference*, (D. Norton, Ed.). Alaska Division of AAAS, vol. II, p. 26-37.



# APPENDIX A: LIST OF SITES OBSERVED DURING 1975.

Site	Description	Date
1J1*	Valdez Terminal	4 August
13J1*	Workpad intersection	3 August
16J1	Squirrel Creek Work Pad	17 July, 19 August
17J1	Disposal site	17 July, 19 August
17J2	Material site	17 July, 20 August
18J1*	Material site	3 August
19J1	Klutina River cut	17 July, 20 August
21J1	Slope near pump station 11	17 July, 20 August
28J1	Pipe storage yard	17 July, 20 August
42J1		
and		
42J2	Workpad cuts	17 July, 20 August
48J1	Workpad cut	7 July
51J1	Workpad, sandy slope	7 July
66J1	Workpad cut	29 July
73J1	Experimental plots	30 July
73J2	Material site	30 July
77J1	Disposal site	30 July
78J1	Road cut	30 July
80J1	Road cut	11 September
81J1	Winter trail	11 September
84J2	Road cut	11 September
88J1	Road cut	11 September
90J1	Road cut	10 September
91J1	Material site	10 September
92J1	Road cut	10 September
97J1	Road cut	10 September
100J1	Trail	10 September
102J1	Workpad cut	26 July
103J1	Material site	26 July
104J1	Material site	26 July
107J1	Road cut	26 July
108J1	Winter trail	26 July
110J1	Road cuts	27 July
110J1a, and J2b		
114J1	Road cuts	27 July
114J2	Silt blanket by road	27 July
119J1	Material site	28 July
122J1	Ice rich road cut	28 July
131J1	Workpad cut	28 July

\*Observed by J. Brown, author did not observe in 1975.

APPENDIX B: ANNOTATED PHOTOGRAPHS OF  
PERMANENT REVEGETATION OBSERVATION SITES—1975-1978.

Missing photographs indicate that sites were not observed during that year unless otherwise noted.

Numbers in parentheses respectively indicate the following: [% litter cover, % live vascular cover, max. height (cm) of vegetation]. Varieties mentioned following parentheses are grasses in seed mix or straw mulch that produced seed.

Figure B1. Site 1J1, slope within area of Valdez terminal. Native species include fireweed (1976), moss (80% cover in 1977), bluejoint setting seed, and alder which by 1978 is overtopping the grass.



a. August 1975, seeded.



c. September 1977 (\_\_, 70, 100) fescue, timothy.



b. September 1976 (\_\_, 70, 100) bluegrass.

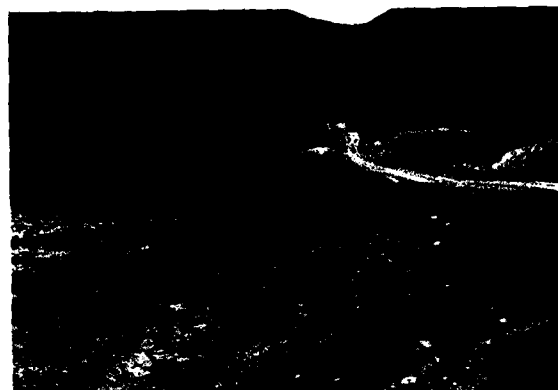


d. September 1978 (\_\_, 80, 170) brome, foxtail, fescue.

Figure B2. Site 5J1, September 1978 (—, 50, 90) annual ryegrass. Workpad on steep slope, jute netting and seeding on slope to stabilize workpad, seeded in 1978.



Figure B4. Site 13J1, workpad intersection with Richardson Highway. Foreground excavated for checking pipeline welds in 1976, regraded and reseeded in late 1977, and revegetated with grass seed mix and VIE transplants to create visual screen in 1978.



a. August 1975, seeded.

Figure B3. Site 6J1, September 1978 (—, 40, 30) annual ryegrass. Steeply sloping workpad at base of Thompson Pass with ditch plugs and other special erosion control measures.



b. September 1976 (30, 80, 100) foxtail. Foreground excavated.





c. July 1977 (—, 60, 170) timothy.

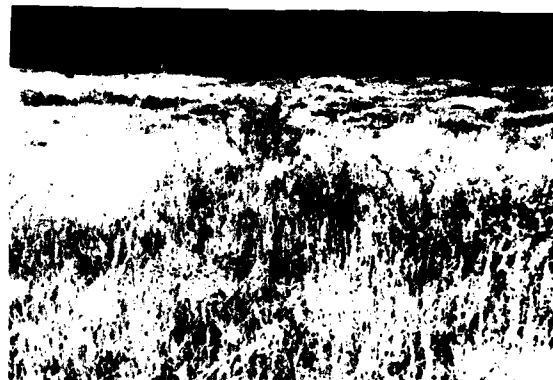


d. September 1978 (—, 50, 120) few brome, fox-tail.

Figure B6. Site 17J1, disposal site 17-3. Brush covered with organic soil, wood fiber mulched, fertilized and seeded, complete cover of vegetation in 1978. Native species include alder, squirreltail, willows, bluejoint, fireweed, and balsam poplar. Native species are continuing to increase in percentage of cover and height.



a. August 1975 (—, 70, 60) seeded.



b. September 1976 (20, 90, 140) foxtail.

Figure B5. Site 16J1, Squirrel Creek slope. Steep north-facing slope with erosion gullies (1975), north-facing slopes terraced and stable with good vegetation cover (1976), vegetative cover reduced though still adequate on north-facing slopes, but severe erosion on south-facing slope (1977), site largely stable (1978). Native species include lamb's-quarters and squirreltail.



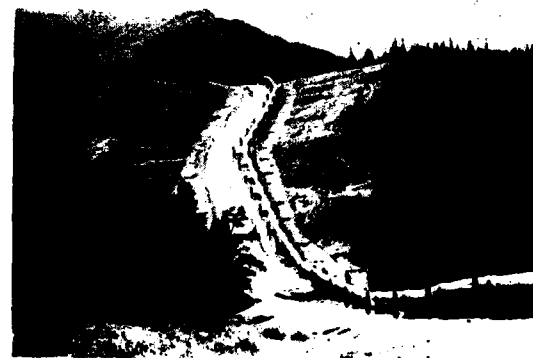
c. September 1977, graded and seeded.



a. August 1975 (—, 60, 25) straw mulch and seed on north-facing slope, annual rye.



d. September 1978 (—, 20, 45) annual rye and fox-tail.

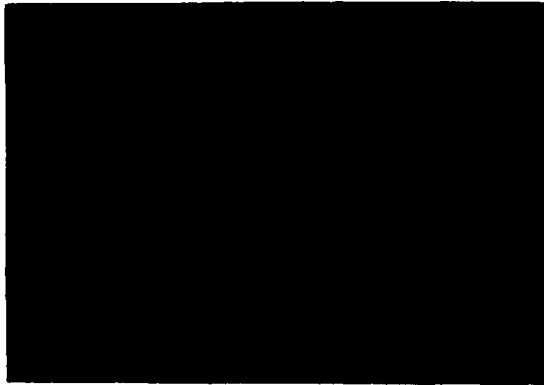


b. September 1976 (—, 90, 100).

Figure B7. Site 17J2, material site 17-5. Disposal materials (fine-grained silts and organics) placed over gravel and reseeded. Willows and alder reinvaded upper slope (1976), alder dominant on slope (1978).



c. June 1977 (\_\_\_, 90, 150), timothy, bluegrass, brome, few fescue.



d. September 1978 (\_\_\_, 10, 150) bluegrass, fescue, foxtail, few brome.



a. September 1975 (\_\_\_, 90, 95) seeded in 1974.



b. September 1976.

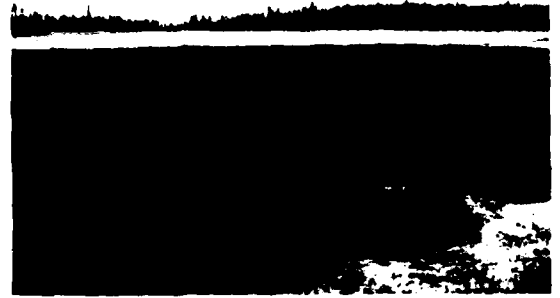
Figure B8. Site 18J1, material site 18-1A, mainly annual rye, barley and lamb's-quarters from straw mulch set seed (1976), mulch stockpiled (1977), access to site blocked, cover reduced but all of site revegetated (1978). Native species: lamb's-quarters, fireweed, balsam poplar and aspen (the last two over 1 m high in 1978).



c. June 1977 (—, 100, 70) annual rye, fescue, timothy.



d. September 1978 (—, 80, 100) foxtail, fescue.



a. September 1976 (—, 70, 65) seeded, annual rye.



b. June 1977 (—, 100, 130) timothy, brome, bluegrass, and few fescue.



c. September 1976 (—, 50, 135) brome, foxtail, fescue and bluegrass.



b. September 1976 (70, 10, 65).

Figure B9. Site 19J1, Klutina River cut beside workpad. Heavily mulched with straw (25–45 cm) to stabilize ice-rich soils (1975), erosion gullies, spruce at base of hill dying from eroded silt (1976), logs and plastic-lined ditches to stabilize workpad (1977), area stable (1978). Native species: lamb's-quarters, fireweed, squirreltail and alder.



c. June 1977 (—, 30, —).

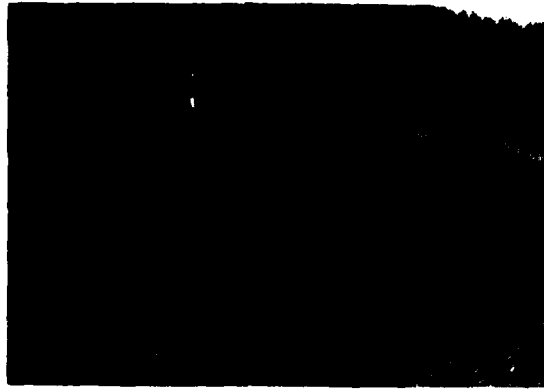


a. September 1976 (—, 60, —) seeded.

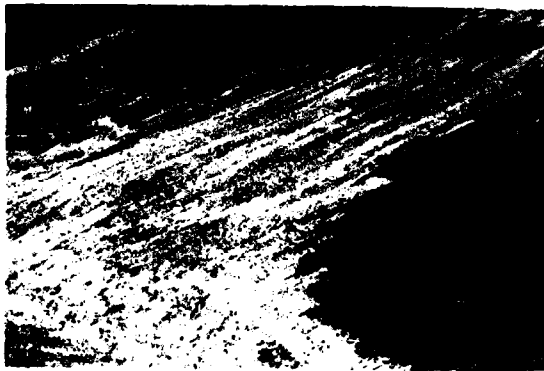


d. September 1978 (—, 10, 60) fescue, annual rye.

Figure B10. Site 21J1, slope beside Pump Station 11. Area partially regraded in 1976 after massive slope failure in 1975, limited revegetation by 1978. Native species: strawberry blight, balsam poplar and a weedy grass (*Bromus tectorum*).



a. August 1976 (—, 20, 8) seeded.



b. September 1976 (90, 10, 30) reseeded.



c. June 1977 (70, 20, 100) brome, fescue, timothy.

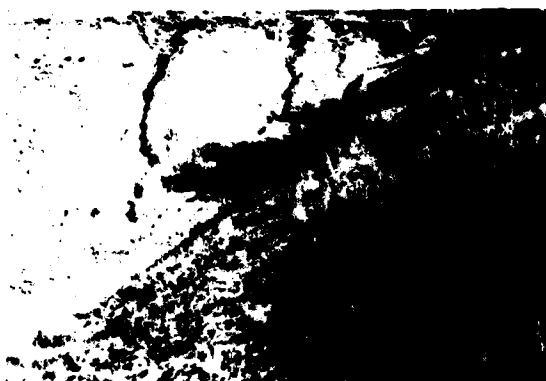


d. September 1978 (—, 40, 115) brome, fescue, foxtail.

Figure B11. Site 28J1, pipe storage yard. Erosion gullies on hydro-seeded slope, barley from straw mulch, revegetated by 1976, entire yard regraded and seeded in 1978. Native species: lamb's-quarters, squirreltail and yarrow.



a. August 1976 (—, 10, 5) seeded.



b. September 1976 (60, 30, 50) annual rye, foxtail.



c. June 1977 (—, 50, 60) fescue, few bluegrass, foxtail.



d. September 1978 (—, 80, 155) foxtail and fescue.

Figure B12. Site 36J1, material site in alpine tundra. Limited vegetative cover and few native species (weedy grass—*Bromus tectorum*). Much higher vegetative cover (80% in 1977 and 50% in 1978) on edge of material site where some organic material was regraded over gravel.



a. September 1976 (—, 40, 36) seeded, annual rye.

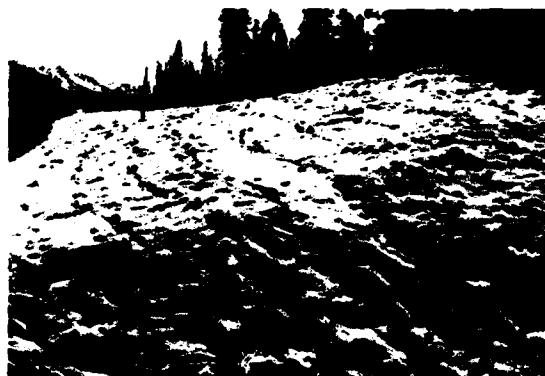


b. June 1977 (—, 20, 100) timothy, fescue, annual rye.



c. September 1978 (—, 20, 60) fescue.

Figure B13. Site 40J1, workpad intersection with Richardson Highway. Seeded, fertilized by hand under excelsior mesh (1976), complete vegetation cover (1976), reduced cover (1977), VIE-spruce and alder transplants (1978). Native species: lamb's-quarters.



a. May 1976 (—, —, —) seeded.



Figure B14. Site 41J1, vegetative mat over massive ice beside VSM. Mat cracked open in 1976 when ice melted, area excavated and covered with gravel in 1977.



b. August 1976 (—, 100, 100) annual rye.



a. May 1976, exposed massive ice.



c. June 1977 (80, 70, 100) foxtail.



b. June 1977.



d. September 1976 (—, 70, 130) foxtail.

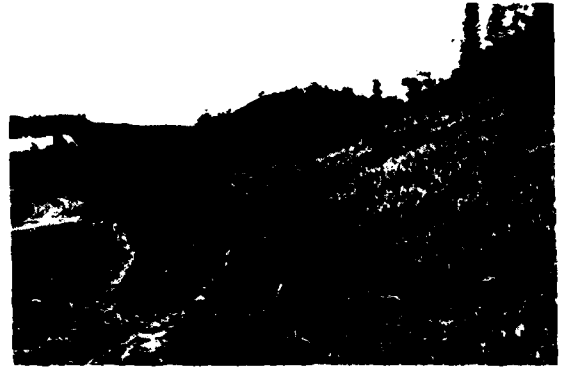
Figure B15. Site 42J1. Cut beside workpad. Foxtail main cover (1976), moss cover 90% (1977), and 60% (1978). Lupine (native) invading by 1978.



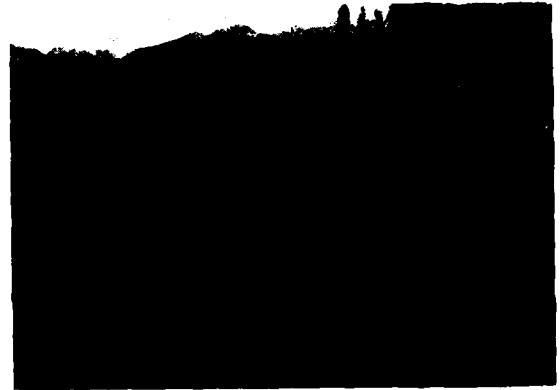
a. July 1976 (—, 10, 8) seeded.



b. September 1976 (—, 80, 120) foxtail, fescue.

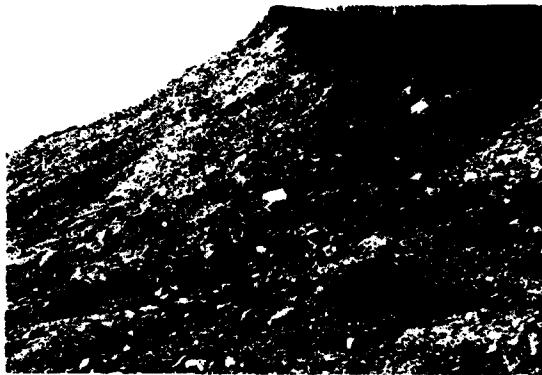


c. June 1977 (—, 50, 100) fescue, foxtail, bluegrass.



d. September 1978 (—, 30, 50).

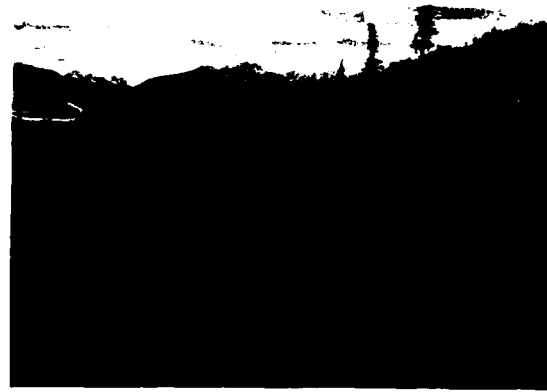
Figure B16. Site 42J2, cut beside workpad. Very little litter produced (1976) but cover adequate in 1977 and 1978.



a. May 1976 (\_\_\_, \_\_, \_\_) seeded 1975. Not observed in summer 1976.



b. June 1977 (\_\_\_, 60, 100) fescue, foxtail, bluegrass.



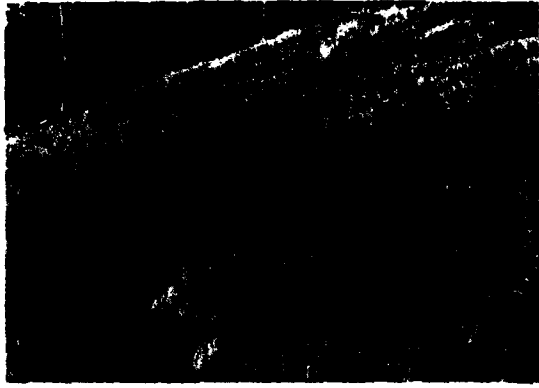
c. September 1978 (\_\_\_, 50, 50) fescue, foxtail.

Figure B17. Site 48J1, slope beside workpad. Hydroseeded after bulldozer tracks used to prepare seedbed (1975), cover and height reduced on upper portion of slope (1977). Native species: fireweed, lamb's-quarters and squirreltail.

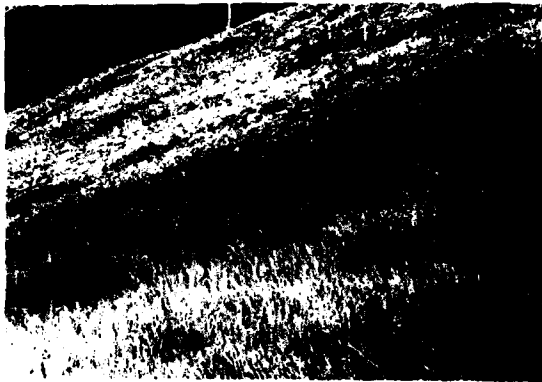


a. August 1975 (\_\_\_, 90, 90) seeded.

Figure B18. Site 51J1, Rosa Creek bluffs, cut for workpad. Sandy slopes stabilized with hay and plastic netting (1975), little regrowth (1976), re-seeded (1977), netting removed (1978). Native species: lamb's quarters.



b. September 1976 (40, 50, 80) foxtail and fescue.



c. June 1977 (\_\_, 100, 70) timothy and fescue.



d. September 1978 (\_\_, 80, 140) bluegrass, foxtail and fescue.



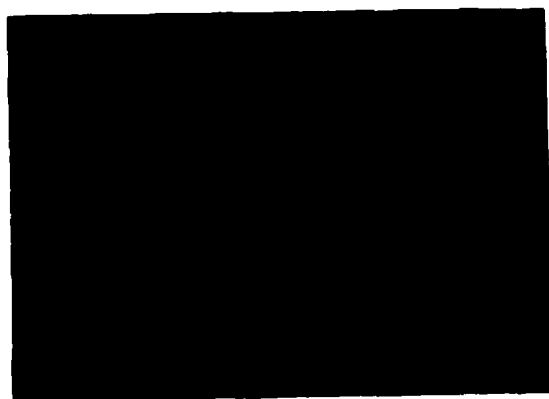
a. August 1975 (\_\_, 60, 90) seeded, barley and oats.



b. September 1976 (100, 10, 25).



c. June 1977 (—, 30, 100) reseeded, timothy.



d. September 1978 (—, 30, 60) bluegrass, fescue, few brome.

Figure B19. Site 61J1, September 1978 (—, 70, 150) brome, foxtail, bluegrass and annual rye. Probably seeded in 1977, good vegetative cover and seed set. Native species: shepherd's purse, fireweed and squirreltail.



Figure B20. Site 66J1, July 1975. Cut slope and workpad were hydroseeded (1975), area re-excavated and revegetation site destroyed for VSM placement (1976).



Figure B21. Site 66J2. Disposal site with high percentage of gravel. Patchy cover with few willows to 30 cm (1977), moss cover 30%, VIE transplants (1978). Native species: willow and squirreltail.



a. May 1976, seeded over organic and fine-grained disposal materials in site.



b. June 1977 (—, 70, 140) timothy, bluegrass.



c. August 1978 (10, 40, 100) foxtail, annual rye.

Figure B22. Site 71J1, material site. Seeded (1976), lower portions of large material site on hilltop regraded (1977), most of site revegetated but patchy vegetative cover (1978). Native species: fireweed and squirreltail.



a. August 1977 (—, 40, 65) bluegrass and timothy.



b. August 1978 (\_\_\_, 30, 105) brome, foxtail, fescue, bluegrass.

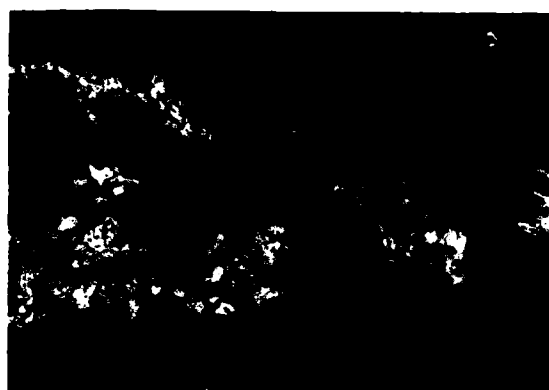


b. August 1976 (\_\_\_, 80, \_\_\_).

Figure B23. Site 73J1. Experimental slope at mile 19.2 on Haul Road. Experimental plots were established in early 1970's to evaluate slope stabilization techniques and have reduced vegetative cover compared to untreated plots. Plots were treated with urethane foam and plastic nets (1975), willows overtopping, urethane still visible (1978). Native species: algae and moss common, fireweed, bluejoint, reedgrass, feltleaf willow to 3 m (1978) and *Polygonum alaskanum*.



c. July 1977 (\_\_\_, 70, 130) timothy.



a. July 1975 (\_\_\_, \_\_, \_\_) annual rye.



d. August 1978 (\_\_\_, 50, 150) foxtail, brome.

Figure B24. Site 73J2, July 1975, seeded, annual rye. Material site, mile 19.3. Lower portion hydroseeded (1975), site re-excavated (1976).



b. June 1976 (100, 20, 15) annual rye, foxtail, brome.

Figure B25. Site 77J1, disposal site 77-48. Aerial seeding produced lush growth of annual rye. Some areas of coarse gravel shoulder were sparsely seeded using wood fiber mulch (1975). Cover reduced, heavy litter cover, equipment ran over some seeded areas (1976), cover still reduced (1977), adequate cover with moss cover 30% (1978). Native species: squirreltail, fireweed, and many willow seedlings (1978).



c. July 1977 (—, 60, —) timothy, fescue, bluegrass.



a. July 1975 (—, —, —) seeded.



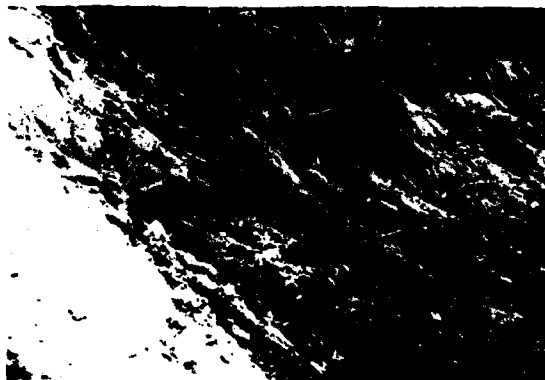
d. August 1978 (80, 50, 117) fescue, foxtail.



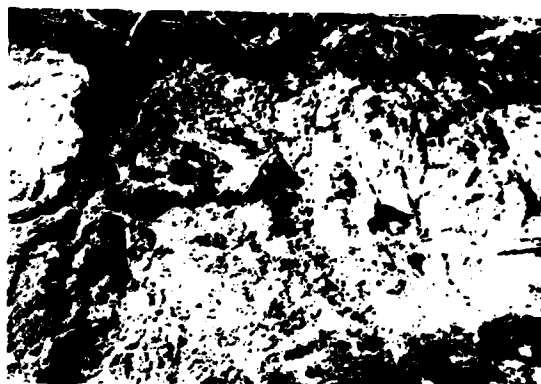
Figure B26. Site 78J1. Ice cut near Yukon River Bridge. Large ice lenses in unseeded silt exposed by road cut. Trees left in place on vegetative mat tear the mat as they are undercut by thaw. Little revegetation but site looks stable (1978). Native species: willows to 3 m (1978), alder, raspberry and strawberry blight.



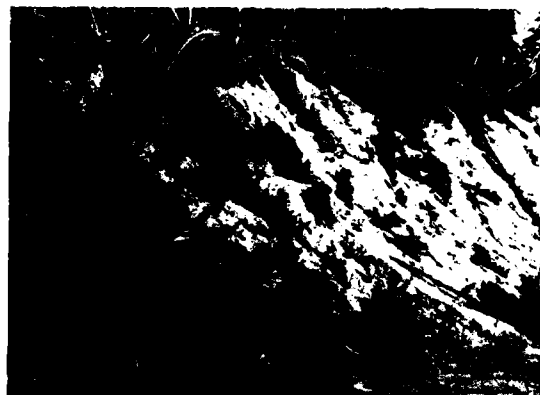
a. July 1975, unseeded.



b. August 1976, some ice exposed.



c. July 1977, no ice exposed, stable.



d. August 1978 (\_\_, 20, \_\_).

Figure B27. Site 79J1, road cut. Upper slope has little cover (1976); more willows on upper slope (1977). Native species: rock harlequin (1976).



a. August 1976 (10, 60, —) seeded (also 1975), annual rye.

Figure B28. Site 80J1, road cut. Germination low on upper slope, willows reinvading (1976), some slumping (1976), most of slope revegetated (1978). Native species: willow, rock harlequin, horsetails, fireweed, prickly rose and squirreltail.



a. September 1975, seeded.



b. July 1977 (50, 70, 100) foxtail, fescue, bluegrass.



b. September 1976 [10, (100-lower, 10-upper), 120] seeded, foxtail, annual rye.



c. July 1977 (—, 80, 160) foxtail, bluegrass, fescue.



d. August 1978 (—, 80, 152) foxtail, brome, bluegrass.

Figure B29. Site 81J1, old trail south of No-Name Creek, vegetative cover removed but part of organic mat remains. Native species dominant (1976), good cover, 80% moss cover (1978). Willows rapidly increasing in size. Other native species: bluejoint reedgrass, horsetail, marsh fleabane and tussock cottongrass.



a. September 1975.



b. September 1976, brome.

Figure B30. Site 84J1. Upland (near alpine) material site. Cover reduced on coarser gravel, reduced cover (1978). *Bromus tectorum*, introduced weedy grass. Native species: shepherd's purse and squirreltail.



c. July 1977 (—, 50, 120) foxtail, bluegrass.



d. August 1978 (40, 50, 139) fescue, foxtail.



a. August 1976 (—, 40, 30) seeded annual rye.



b. July 1977 (40, 30, 60) foxtail, annual rye, fescue, bluegrass.



c. August 1978 (20, 20, 30) brome, fescue, foxtail, annual rye.

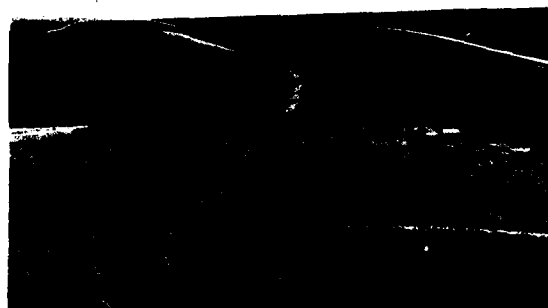
Figure B31. Site 84J2, September 1975. Road cut, west site of road hydroseeded with wood fiber mulch (1975). Some barley and lamb's-quarter germinating from hay, site covered over (1976).



Figure B32. Workpad, weathered granites, seeded. Scattered fireweed, thick covering of wood cellulose fiber mulch (1976), good vegetative cover (1977), patchy cover (1978). Native species: fireweed, squirreltail, pineapple weed.



a. August 1976 (—, 10, 8) seeded.



b. August 1977 (—, 70, 100) foxtail, fescue bluegrass.



c. August 1978 (20, 20, 95) brome, foxtail, annual rye, bluegrass.

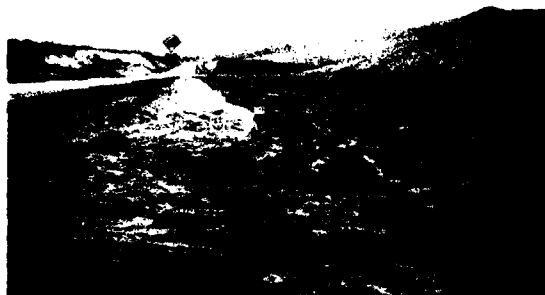


b. July 1977 (—, 50, 100) seeded.

Figure B33. Site 87J1, material site and road cut. Fine-grained soils deposited on site. Subsoil spread over material site (1976); evenly distributed vegetative cover (1978).



c. August 1978 (20, 50, 135) foxtail, brome, fescue.

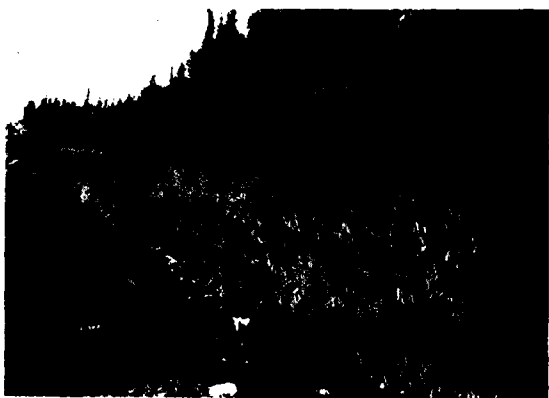


a. July 1976, disposal material spread.

Figure B34. Site 88J1, road cut. One-third of site seeded with good cover (1975), foxtail dominant (1976), assorted seed heads (1977). Native species: alder and willow seedlings (1978).



a. September 1975, seeded southern part of cut bank.



b. August 1976 (20, 60, 120) seeded all of cut, foxtail (from 1975), annual rye.



c. July 1977 [40 (40 from 1975, 80 from 1976) 150] foxtail, bluegrass, fescue.



d. August 1978 (50, 20, 130) foxtail, brome, fescue.

Figure B35. Site 90J1, road cut. Hydroseeded over weathered granite substrate (1975), foxtail dominant (1976), some patches of vegetation appear to be drying out and dying (1977), heavy litter in patches (1978). Native species: rock harlequin, aspen and fireweed.



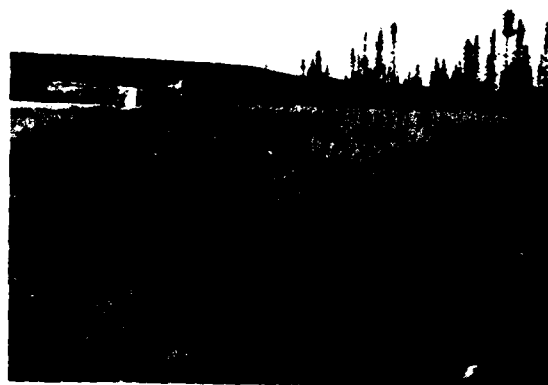
a. September 1975, seeded.



b. August 1976 (10, 100, 120) foxtail, few annual rye.



c. August 1977 (—, 80, 100) foxtail, bluegrass, fescue.



d. August 1978 (90, 40, 122) foxtail, brome, fescue.



Figure B36. Site 91J1, material site 91-3. Probably seeded in 1974. Organics mixed with weathered granite, vascular plant cover increased, but still low and discontinuous, moss cover 50% (1978). Native species: fireweed, willows, balsam poplar, sedge, yarrow and birch.



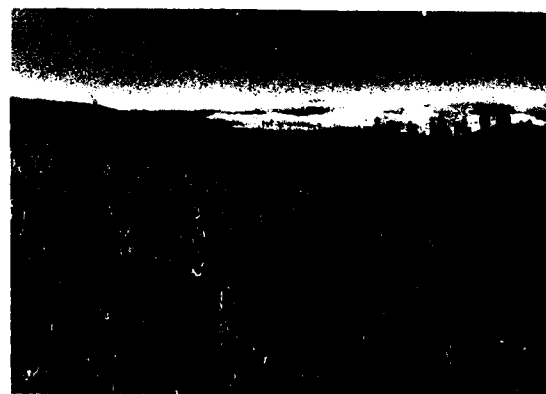
a. September 1975 (\_\_\_, 20, \_\_\_).



b. August 1976 (10, 30, 65) fescue, annual rye, fox-tail.



c. July 1977 (\_\_\_, 20, 100) brome.

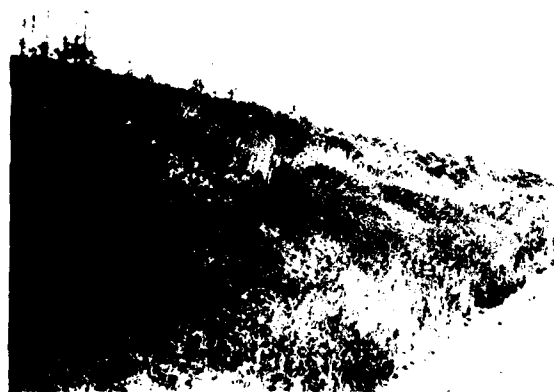


d. August 1978 (\_\_\_, 20, 120) foxtail, brome.

Figure B37. Site 92J1, road cut. Cottongrass tussocks and black spruce on overhanging mat, upper mat stable (1976), lush cover, probably reseeded, browning of foliage on upper slope, detached cottongrass tussocks rooting downslope, extensive moss coverage on toe of slope (1977). Other native species: fireweed, willows to over 1 m, and squirreltail.



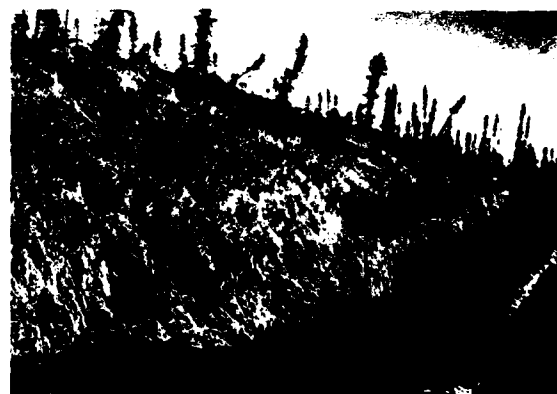
a. September 1975, seeded.



b. August 1976 (—, 90, 120) foxtail.



c. July 1977 (—, 100, 160) foxtail, annual rye, bluegrass.



d. August 1978 (—, 90, 181) brome, foxtail.

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REVEGETATION AND SELECTED TERRAIN DISTURBANCES ALONG  
THE TRANS-ALASKA PIPELINE 1975-1978(U) COLD REGIONS  
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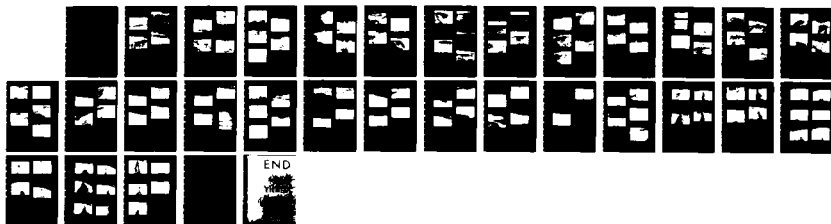
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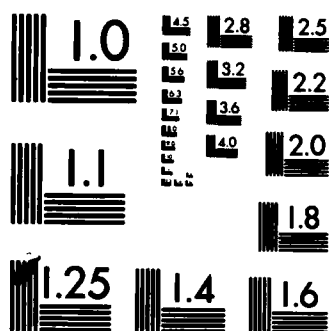
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Figure B38. Site 97J1, road cut. Good cover except on slope (1976), 30% moss cover (1978). Native species: squirreltail.



a. September 1975, seeded.



b. August 1976 (10, 70, 100) reseeded, annual rye, foxtail.



c. July 1977 (—, 60, 130) fescue, foxtail, brome, timothy.

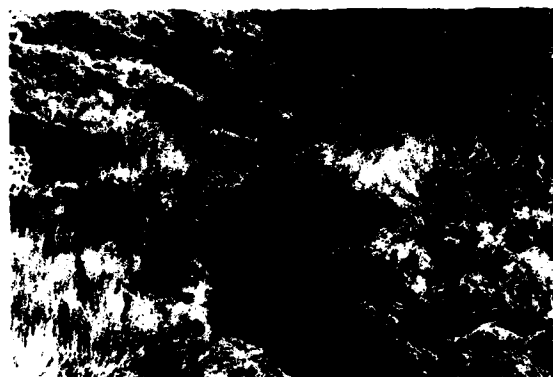


d. August 1978 (60, 30, 82) brome, fescue.

Figure B39. Site 97J2, road cut. Unstable cut in ice-rich soils, vegetation mat breaking (1976), bank largely stabilized, trees cut on overhanging vegetative mat (1977), no melting ice, lush revegetation (1978). Native species: horsetail, birch and willow.



a. June 1976, seeded.



b. August 1977 [\_\_, 100 (lower slope), 130] foxtail.



c. August 1978 [\_\_, 100, 143] foxtail.

Figure B40. Site 100J1, trail. Bladed trail seeded and mulched with straw (1975), good revegetation in background (1976), heavy litter, lower portion flooded in May (1977). Numerous native species: willow, moss, strawberry blight, squirreltail, fireweed, horsetail, tussock cottongrass, sedges, balsam poplar and rushes.

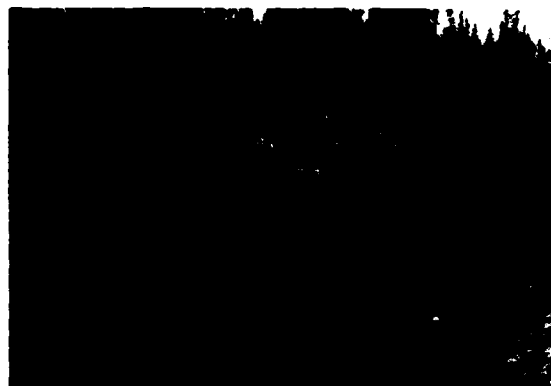


a. September 1975, seeded.

Figure B41. Site 101J1, road cut. Mulched with straw and hydroseeded (1975), grass cover overtopping straw (1976), straw largely covered by grass growth (1977), good vegetative cover but no native species (1978).



b. August 1976 (20, 80, 10) seeded.



a. September 1975, seeded.



c. August 1977 (80, 40, 75) bluegrass, annual rye.

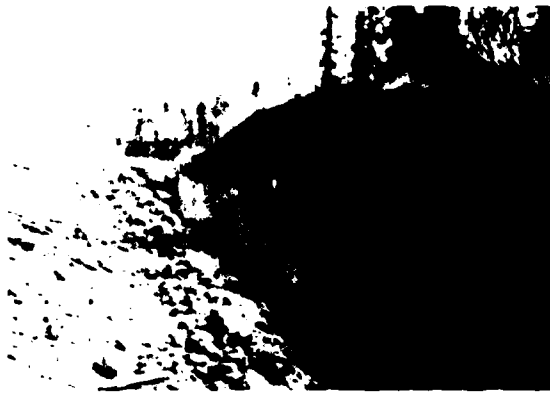


b. August 1976 (\_\_, 50, 90) foxtail.



d. August 1978 (70, 40, 60) fescue.

Figure B42. Site 102J1, cut slope beside workpad. Hand-seeded under excelsior mesh (1975), minimal growth under excelsior (1976), bottom of slope stabilized with rock (1977), cover gradually increasing through excelsior (1978). Native species: lamb's-quarters, bluejoint reedgrass, tussock cottongrass, willow, Labrador tea and cranberry.



c. August 1977 (40, 80, 130) foxtail, fescue, bluegrass.



d. August 1978 (80, 70, 77) foxtail, fescue.



a. September 1975, seeded.



b. August 1976 (\_\_, 10, 30) annual rye.



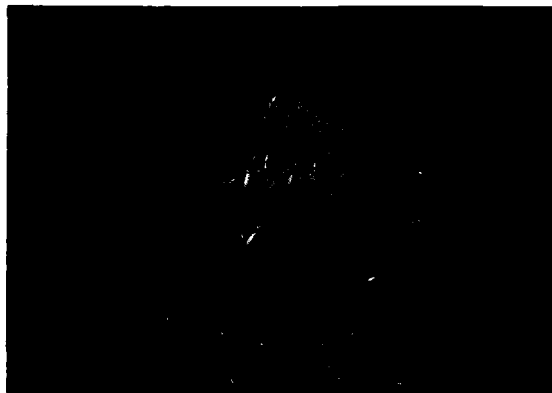
Figure B43. Site 102J2, spur dike in floodplain of river. Seeded (1975), mulched with straw (1976). Note barley seed heads, barley from straw; heavy litter but low live cover (1977, 1978). Native species: lamb's-quarters and squirreltail.



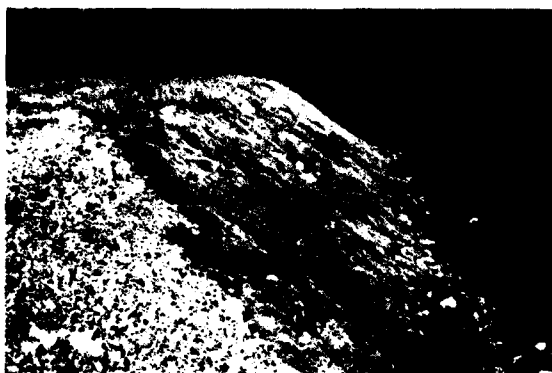
c. August 1977 (—, 20, 100) foxtail, fescue, timothy, annual rye.



d. August 1978 (—, 40, 101) fescue, foxtail, bluegrass.



a. August 1976 (—, 80, 65) annual rye.



b. August 1977 (100, 40, 100) foxtail.



c. August 1978 (80, 20, 153) fescue, foxtail.

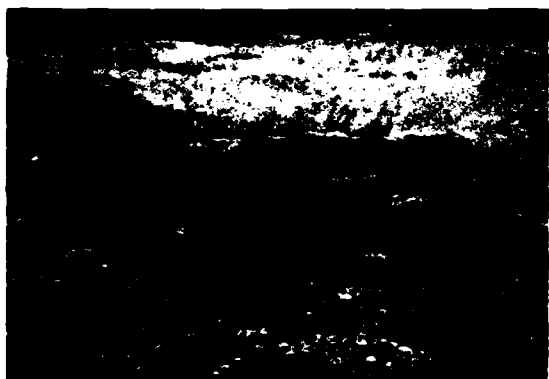


b. August 1976 (10, 10, 65) annual rye, fescue, fox-tail.

B44. Site 103J1, material site 103-0. Vegetative cover, patchy especially on slopes and areas of coarse gravel (1976), regraded, 15 to 20 cm of top-soil brought into site (1977), spruce transplants and seedlings added to revegetated areas, vegetative cover sparse but improved (1978). Native species: squirreltail.



c. August 1977, reseeded.



a. September 1975, seeded.



d. August 1978 (\_\_, 30, 78) annual rye, timothy.

Figure B45. Site 104J1, material site. Seeded area along stream bank heavily grazed by moose, oats produced from seed in straw mulch (1975), area reseeded (1977), rock dike installed adjacent to streambed and debris scattered (1978). Native species: lamb's-quarters, squirreltail and blue-joint reedgrass.



a. September 1975, seeded.



b. August 1976 (100, 100, 120) foxtail.



c. July 1977 (\_\_\_, 90, 110) reseeded, mostly fescue, foxtail.

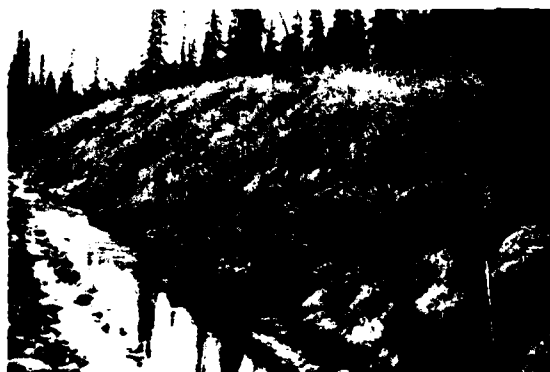


d. August 1978 (\_\_\_, 60, 83) fescue, foxtail, timothy.

Figure B46. Site 107J1, road cut of fine-grained silts. Trees cut on vegetative mat to allow slumping over road cut (1975), bank stable with good vegetative cover (1977). Native species: squirrel-tail, lamb's-quarters, bluejoint reedgrass.



a. September 1975 (—, 90, —) seeded.



b. July 1977 (—, 40, 80) reseeded, annual rye.



c. August 1978 (60, 50, 111) foxtail, fescue, bluegrass.



d. August 1978 (90, 80, 81), foxtail, fescue.

Figure B47. Site 107J2. Workpad and coarse substrate (gravel). Reseeded near treeline, low percentage of ground cover (1977), fairly heavy litter in foreground (1978).

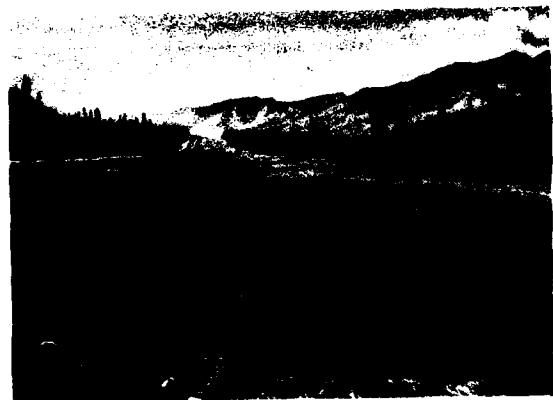


a. August 1976, seeded, annual rye.

Figure B48. Site 108J1, winter trail. Probably seeded in 1974. Tussock cottongrass flowering in background (1975), native shrubs increasing (1977), good cover on trail, 60% moss cover (1978). Native species: willow, dwarf birch, blueberry, sedges and fireweed.



b. July 1977 (—, 40, 80) reseeded, annual rye.



c. August 1978 (60, 50, 111) foxtail, fescue, bluegrass.



a. August 1975, annual rye.



b. August 1976 (—, 70, 65) fescue.

Figure B49. Site 108J2, slide beside road. Mulched with straw (1975), live cover increased, oats and barley from straw (1976), stable, gravel covers upper portion of slump (1977), some native species (1978). Native species: lamb's-quarters, squirrel-tail, fireweed, shepherd's purse, coltsfoot and Melilotus.



c. July 1977 (—, 70, 80) fescue, bluegrass.



a. July 1975, seeded.



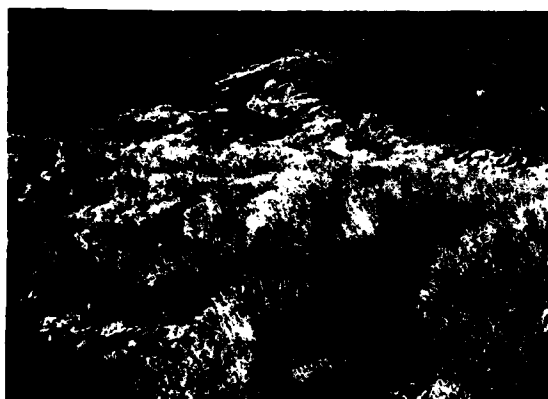
d. August 1978 (—, 70, 103) bluegrass, fescue.



b. August 1976 (100, 60, 65) straw, foxtail.



c. July 1977 (50, 70, 130) foxtail, annual rye, bluegrass.



d. August 1978 (—, 70, 90) foxtail, fescue.

Figure B50. Site 109J1, August 1978 (—, 60, 87) foxtail, timothy, bluegrass. Reseeded workpad with willow cuttings (1977), good growth of grasses, no cutting survival (1978).



Figure B51. Site 110J1, road cut covered with plastic-backed excelsior mesh. Seeded (1975), melting behind road cut (1976), growth still reduced (1977), detached clumps of native vegetation re-establishing over mesh (1978). Native species: coltsfoot, cottongrass, sedges and tall arcticgrass.

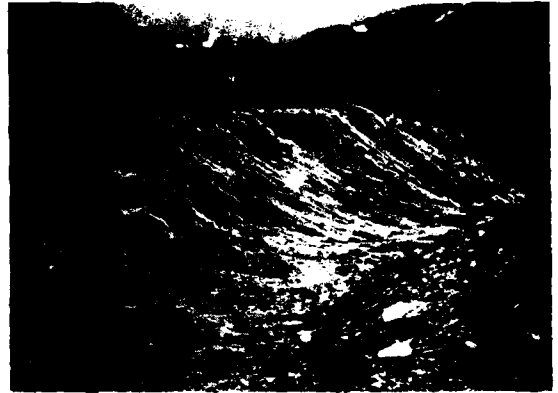


a. August 1976 (—, 10, —).

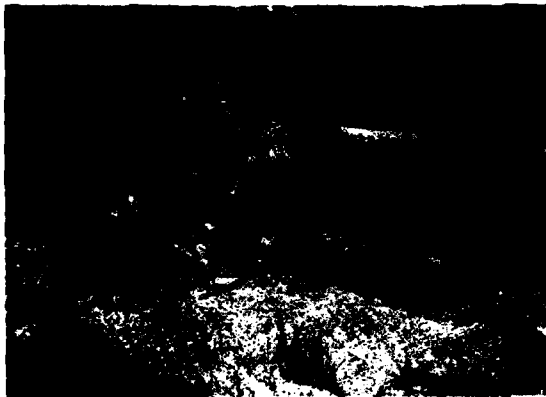
Figure B52. Site 110J2a, road cut, east side at base of Atigun Pass. Little growth (1976), wet and slumping despite excelsior mesh (1977), little growth but seems stable (1978). Native species: tall arcticgrass.



b. August 1977 (—, 20 (patchy), 60] foxtail, bluegrass.



a. June 1976 (—, 10, 30).



c. August 1978 (—, 30, 50) foxtail, fescue.



b. August 1977 (—, 10, 30) foxtail, fescue.



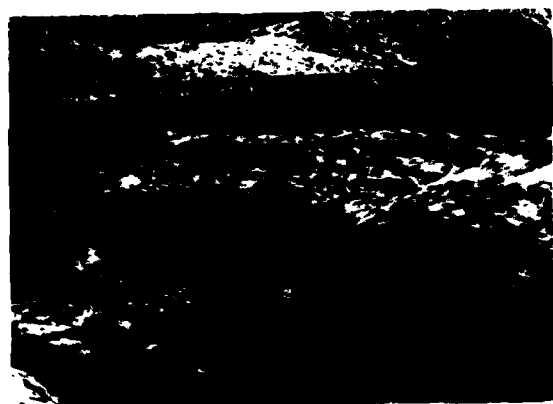


c. August 1978 (—, 10, 30).



b. August 1976 (—, 40, 65) foxtail.

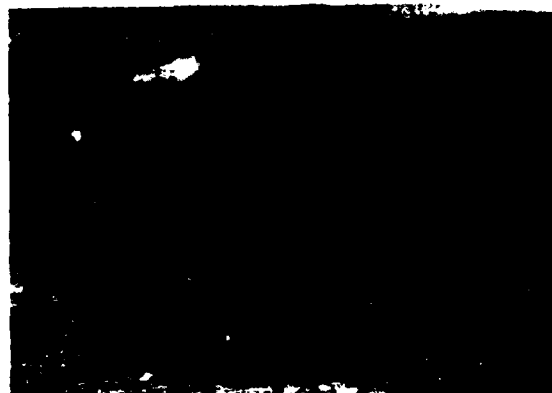
Figure B53. Site 110J2b, road cut, west side at base of Atigun Pass. Excelsior mesh, snow-covered (1975), good cover at top of bank (1976); patchy cover through mesh (1977), gravel thrown over slope (1978).



a. July 1975, seeded.



c. August 1977 (—, 30, 75) foxtail, fescue.



d. August 1978 (—, 20, 73) fescue, foxtail, bluegrass.

Figure B54. Site 114J1, Atigun River road cut. Hydroseeded and mulched (1975), minimal growth over sandy soil with buried peat (1976), improved (40%) growth on lower slopes (1977), cover slowly increasing (1978).



a. July 1975, seeded.



b. August 1976 (10, 60, 80) annual rye, fescue.



c. August 1977 (\_\_, 10, 60) fescue.



d. August 1978 (\_\_, 20, 60) foxtail, fescue.

Figure B55. Site 114J2, silt blanket. Fine-grained disposal material placed along road shoulder and hydroseeded (1975), probably reseeded, dense growth and high seed production (1976, 1977), vegetation persists (1978). Native species: tall arcticgrass.



a. July 1975, seeded.



b. August 1976 (\_\_\_, 70, 80) annual rye, foxtail.



c. August 1977 (\_\_\_, 80, 70) bluegrass, fescue, foxtail.



d. August 1978 (\_\_\_, 90, 72) fescue, foxtail.

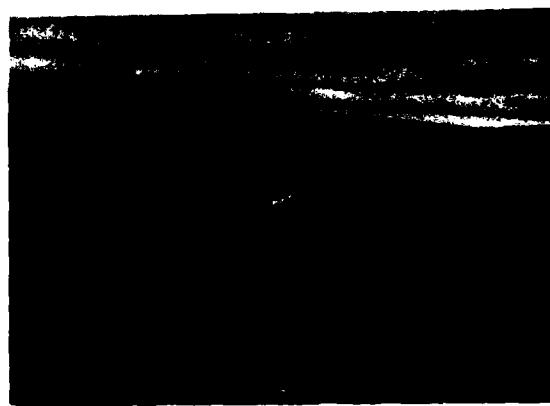
Figure B56. Site 117J1, disposal site. Fine-grained spoil material, seeded, fertilized, harrowed (1976), reduced growth of perennials (1977), good but patchy cover (1978). Native species: yarrow, squirreltail and strawberry blight.



a. August 1976 (—, 60, 45) seeded, annual rye.



b. July 1977 (40, 50, 25).



c. August 1978 (—, 40, 96) fescue, bluegrass.

Figure B57. Site 119J1, material site. Hydroseeded and mulched with straw (1975), scattered vegetation (1976), vegetative clumps beginning to coalesce (1977). Native species: lamb's-quarters, willow, tall arcticgrass, cloudberry, horsetail.



a. July 1975, seeded.

Figure B58. Site 119J2, material site 119-4. Regraded and seeded (1976), regrowth of perennials early in season (1977), boundary of adequate vegetation sharply defined near edge of pit where there are organics plus fine-grained spoil (1978). Native species: coltsfoot, willows, and squirreltail.



b. August 1976 [90 (straw), 10, 20] fescue.



a. August 1976 (\_\_, 10, 45) seeded.



c. August 1977 [80 (straw), 20, 30] fescue, bluegrass.



b. July 1977 (\_\_, 40, 40) bluegrass, fescue.



d. August 1978 (\_\_, 20, 85) fescue, bluegrass.



c. August 1978 (\_\_\_, 10, 35) fescue, bluegrass (\_\_\_, 40, 60) on fines at edge.



b. July photograph, August data, 1977 (10, 40, 20) bluegrass, fescue.

Figure B59. Site 121J1, disposal site. Both fine- and coarse-grained material (1976), organics support much higher cover (70% vs 10%) (1977), good vegetative cover (20% moss cover) on all but coarse soils (1978). Native species: yarrow, squirreltail, fireweed and willow.

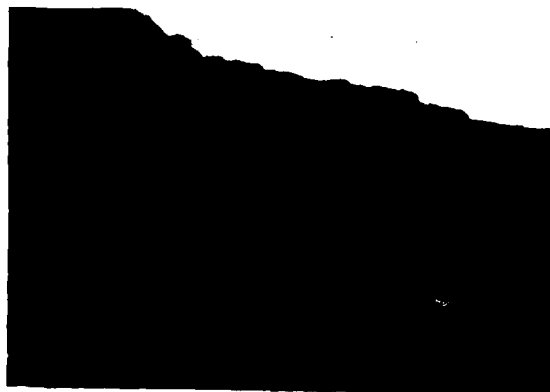


c. August 1978 (\_\_\_, 40, 80) fescue, bluegrass.



a. August 1976 (\_\_\_, 20, 30) seeded.

Figure B60. Site 122J1, road cut—massive ice. Soils unstable, ice wedges exposed (1975), dense annual rye along lower portion (1976), ice no longer exposed (1977), site stable, grass cover persisting (1978). Native species: cottongrass, willow and dwarf birch.



a. July 1975, seeded.



b. August 1976 (—, 40, 80) annual rye.



c. August 1977 (—, 80, 80) fescue, bluegrass.



d. August 1978 (—, 90, 80) fescue, bluegrass.

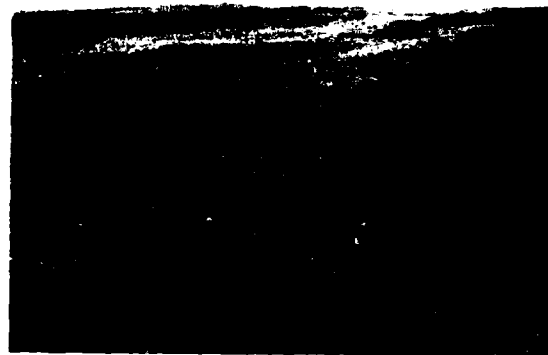
Figure B61. Site 127J1, material site 127-2.1B. Large cracks and erosion developed with little vegetative cover (1975), good cover on organic disposal, reduced on coarse gravel (1976), site regraded, aerially seeded (1977), cover still patchy but overall higher than earlier efforts (1978).



a. July 1975, seeded.



b. August 1976 (10, 50, 65) seeded.



c. August 1977 (—, trace, 10).



d. August 1978 (—, 40, 30), bluegrass, fescue.



Figure B62. Site 129J1, straw over eroded silts from fuel gas line. Dramatic growth on test plot where straw removed and probably tall arctic-grass seeded (1976), area flooded during breakup (1977), growth still better on test plot but difference not as dramatic (1978).



a. August 1976 (—, 60, 150—test plot; —, 10, 3—uncleared), seeded.



b. July 1977 (—, 80, 50; —, 60, 15).



c. August 1978 (30, 80, 75; 50, 80, 35), tall arctic-grass on test plot.

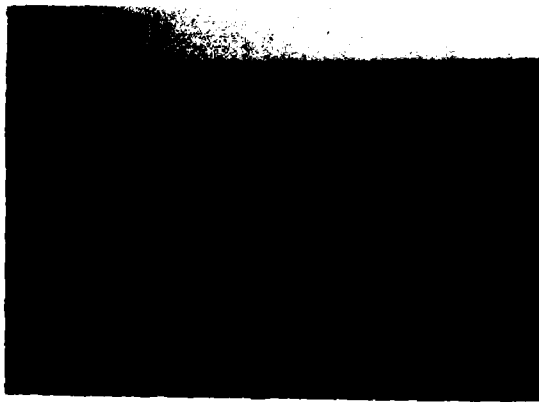
Figure B63. Site 131J1, July 1975. Site was covered by gravel in August 1976. No photograph taken. Cut beside workpad, slumping despite excelsior mesh and straw mulch.





*b. August 1978 (—, 50, 15) few bluegrass.*

*Figure B64. Site 133J1, workpad. Some organics and fines patchily distributed over gravel, vegetative cover patchy, note reduced height of vegetation (1978).*



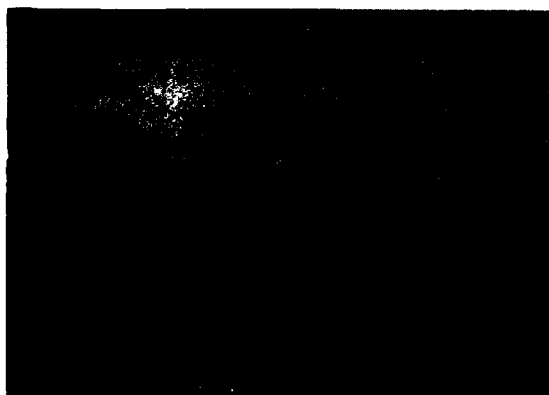
*a. July 1977 (—, 30, 15) seeded.*

## APPENDIX C: PHOTOGRAPHIC RECORD OF FUEL GAS LINE OBSERVATION SITES

### Section A. Foothills, blasted trench



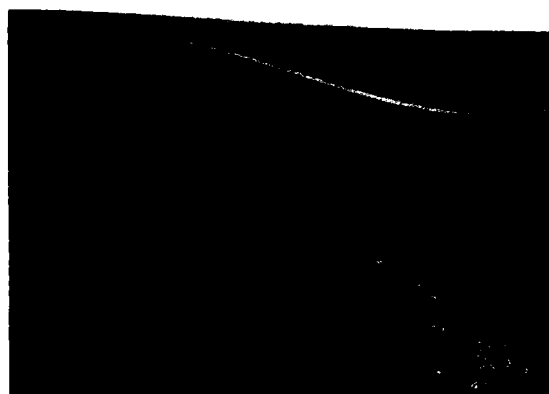
*Figure C1. Site 116G1, August 1976 (note 100% cover of debris between trench and road.).*



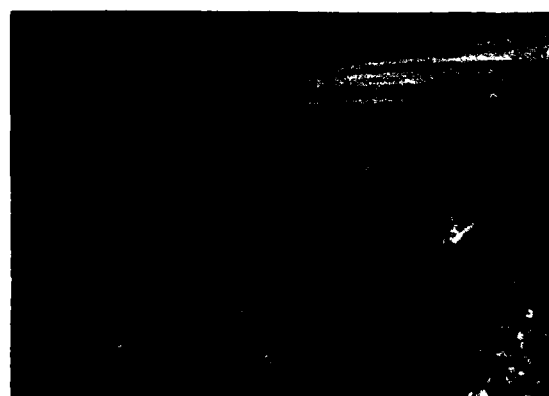
*Figure C2. Site 116G1, August 1978 (note 10% cover of reseeded grasses over trench).*



*Figure C3. Site 117G1, August 1976 (note up to 90% cover by debris on either side of trench).*



*Figure C4. Site 117G1, August 1978 (note 30% cover over trench by seeded grasses).*



*Figure C5. Site 118G1, August 1976.*



*Figure C6. Site 118G1, August 1978, native species beside ditch and reseeded areas over trench growing well.*



*Figure C8. Site 124G1, August 1978 (note increased seed production by native grasses adjacent to trench).*

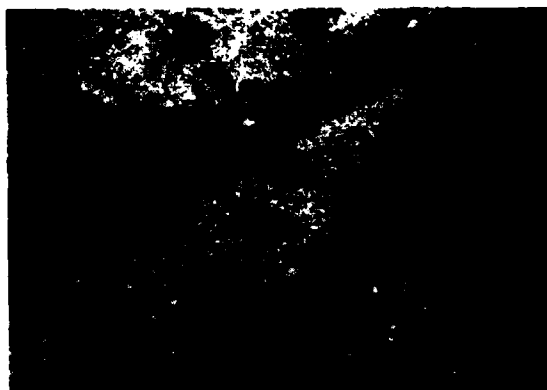
#### **Section B. Foothills, Roc-Saw trench**



*Figure C7. Site 124G1, August 1976 (looking south).*



*Figure C9. Site 124G2, August 1976 (looking south).*



*Figure C10. Site 124G2, August 1977, between trench and road (note gravel covering vegetation, cottongrass tussocks growing through gravel, moss cover reduced).*



*Figure C12. Site 124G3, August 1976.*



*Figure C11. Site 124G2, August 1978 (looking south). Note lush growth of willows and grasses adjacent to trench.*



*Figure C13. Site 124G3, August 1978 (extensive flowering of native grasses adjacent to trench).*



*Figure C14. Site 124G4, August 1976. Only snowpad constructed, not trenched.*



*Figure C17. Site 125G1, August 1978.*



*Figure C15. Site 124G4, August 1978 (note growth of seeded grasses over trench).*



*Figure C18. Site 125G2, August 1976. Only snowpad constructed, no trenching.*



*Figure C16. Site 125G1, August 1977 (note growth of seeded grasses over trench).*



*Figure C19. Site 125G2, August 1978, debris still visible but regrowth is covering some of it.*



*Figure C20. Site 127G1, August 1976, formerly beneath snowpad (note abraded and broken cotton-grass tussocks).*



*Figure C22. Site 127G1, August 1978, looking south (note good growth of seeded grasses over trench where it is lower and hence wetter).*

#### **Section C. Coastal Plain, Roc-Saw Trench**



*Figure C21. Site 127G1, August 1978 (note increased growth of native species adjacent to seeded and fertilized trench, little growth of seeded grasses over trench).*



*Figure C23. Site 128G1, August 1976, relatively well-defined trench.*

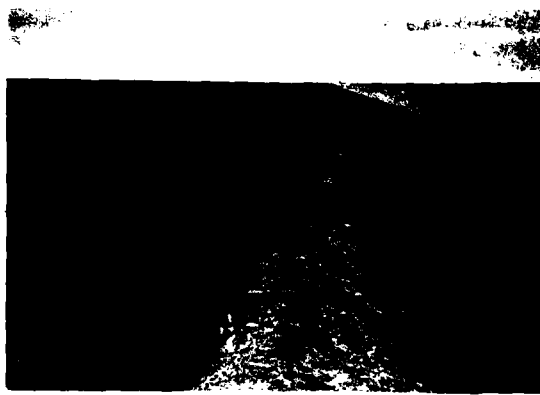


Figure C24. Site 128G1, August 1977.

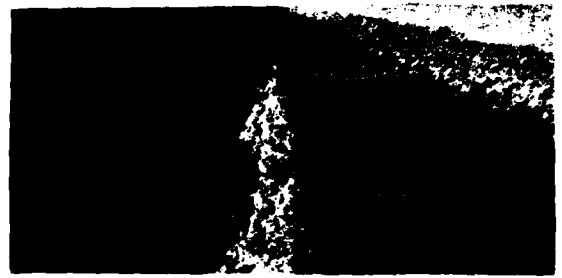


Figure C27. Site 129G2, August 1976, well-defined trench.



Figure C25. Site 129G1, August 1976 (note some gravel washed across trench opposite culvert in background).

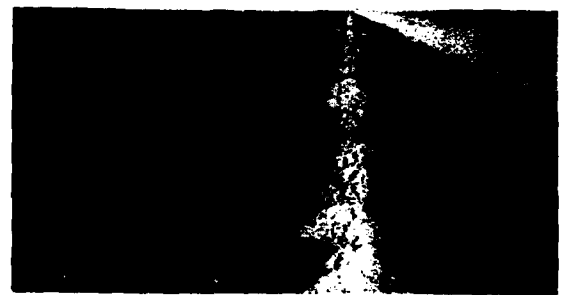


Figure C28. Site 129G2, August 1977, debris partially covered by vegetation between road and trench.



Figure C26. Site 129G1, August 1977 (note gravel opposite culvert in background).

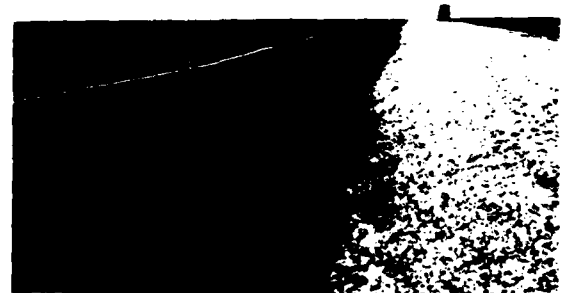
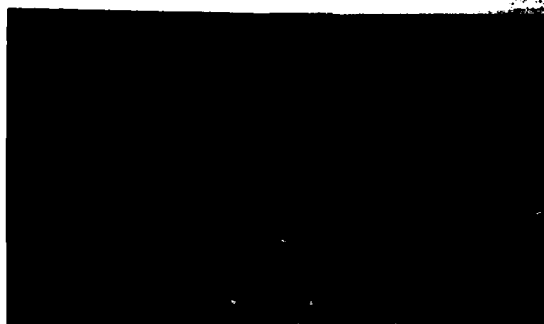


Figure C29. Site 130G1, August 1976, only snowpad constructed, no trenching.





*Figure C30. Site 130G1, August 1978, little growth of seeded grasses on elevated, well-drained gravels over trench.*



*Figure C33. Site 130G3, August 1977, trench fairly clean-cut.*



*Figure C31. Site 130G2, August 1977, some gravel beside trench.*



*Figure C34. Site 130G3, August 1978, minimal re-vegetation over trench.*



*Figure C32. Site 130G2, August 1978 (note good growth of seeded grasses).*

A facsimile catalog card in Library of Congress MARC format is reproduced below.

Johnson, Lawrence A.

Revegetation and selected terrain disturbances along the trans-Alaska pipeline, 1975-1978 / by Lawrence A. Johnson. Hanover, N.H.: U.S. Cold Regions Research and Engineering Laboratory; Springfield, Va.: available from National Technical Information Service, 1981.

vii, 124 p., illus.; 28 cm. ( CRREL Report 81-12. )

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Bibliography: p. 54.

1. Arctic regions. 2. Erosion control. 3. Grasses. 4. Pipelines. 5. Restoration. 6. Revegetation. 7. Shrubs. 8. Soil erosion. I. United States. Army. Corps of Engineers. II. Army Cold Regions Research and Engineering Laboratory, Hanover, N.H. III: Series: CRREL Report 81-12.

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